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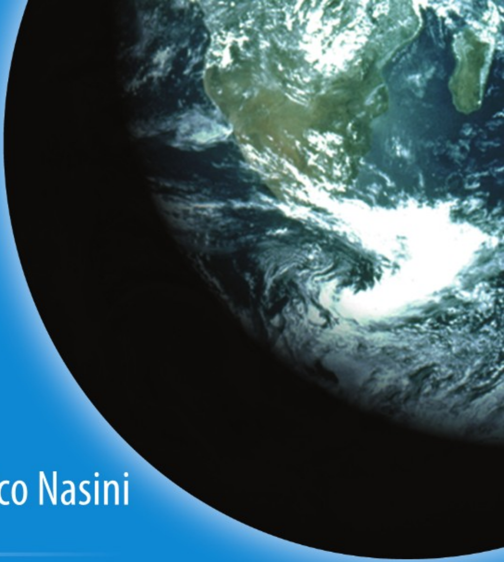

Marcello Spagnulo
Rick Fleeter
With Mauro Balduccini and Federico Nasini

Space Program Management

Methods and Tools

Space
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SPACE PROGRAM MANAGEMENT

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Dedication

Non est ad astra mollis e terris via
(It is not easy the way for the stars)
Seneca, from Hercules Furens

Thanks to Daniela and Claudia for making
brighter my way for the stars
Marcello Spagnulo

Foreword

What is a major project or program? The construction of an international gas pipeline, the development and commercial launch of a new type of aircraft for transporting passengers, the building of the tunnel under the English Channel between France and England, the planning and building of a nuclear power plant, the on-ground manufacturing of the components of the International Space Station and their launch and assembly in space are all examples of major programs.

All of these achievements were made possible through enormous investments in research and development and major industrial programs that have very distinct features: major financial investment and long-term time commitment, cutting edge innovation, international partnerships, and ever-increasing levels of technological risk.

Space programs, by their very nature, are part of the scientific and industrial activities we have just illustrated.

Space programs therefore require huge investments and it falls upon governments, through their space programs, to provide the funding for their realization. Private businesses can only begin to invest in space systems when an application from a space program becomes commonly used and is valuable to a large market.

This particular feature of the space sector, in addition to creating a barrier to competition, requires public investors to be fully aware of their country's scientific and industrial strategies and to synthesize these scientific, industrial, and political aspects.

These considerations are even more important in international cooperation, where national interests must co-exist with compromises resulting from political negotiations, which prevail over technological or scientific issues.

The decision-making process involved in a space program is therefore complex and varied: the national space agency plays a crucial role in protecting and enhancing both previous as well as future national investments.

Once it has been decided to start up a space program, proper management becomes crucial and can be summarized in two key factors: cost management and time management.

The essence of management therefore lies in the ability to plan, control, and intervene in the development of the project to maintain time schedules and costs established at the program's start-up.

This capability involves two things: from the industrial viewpoint, it is the capability of managing production properly (in accordance with the time schedule and costs established in the contract), and from the agency's viewpoint, as the capability of knowing how to invest through proper planning.

If the first aspect is easily identifiable (industrial management), the second one is not so easy to recognize, but has an enormous impact on program management.

It involves the agency's ability to plan and invest in time schedules and proper modalities, which are consistent with national and international strategies and which do not impede or anticipate scientific or industrial activities that could cause imbalances in public expenditures.

These imbalances can generate surpluses or liabilities that affect the agency's management, which has the responsibility of investing in long-term and highly strategic programs.

Here is where space program management not only involves proper management methods and tools, but also *governance* of the space sector for planning and strategic guidance of public investment.

Based on these brief considerations, the space sector is unique and the management of space programs is a very complex task. In the past, the sector's decision-making and management processes were a reference model for other industrial sectors because of their distinctive technological and development nature.

The methods and tools dealt with in this book aim at drawing the reader closer to the specific nature of this sector. It illustrates how the conception, management, financing, and start-up of a space program are among the most complex of human activities and how space history has influenced today's programs.

It is an area where highly qualified, specialized men and women are an essential and crucial prerequisite.

President of the Italian Space Agency ASI Enrico Saggese

Preface

I had the privilege of returning, to the International Space Station (ISS) for the third time from 16 May to 1 June 2011 after the "Marco Polo" mission in 2002 and the "Eneide" mission in 2005. This time I did not go with the Russian Soyuz spacecraft, but I flew on board the Space Shuttle Endeavour, which took off from the hot, sunny Cape Canaveral launch base in Florida.

I spent 16 incredible days on board the Endeavour and the ISS, experiencing events and surroundings I had known years before, which were always new, fascinating, and captivating.

Sixteen work days that were the result of years and years of work, training, and testing; in other words planning and preparation.

This is why reading and writing a preface for a book which concerns space programs, after experiencing them first-hand, evokes a strange feeling in me.

After having experienced a certain kind of training for many years, made up of methodically planned intense activity and having spent many days on board the ISS, I am now reading behind-the-scenes activities and methods with a mixture of curiosity, interest, and reflection.

Space, as a sector, is continuously evolving and becoming a work environment open to everyone. It provides an opportunity for growth and development; however, the absolute methodological and management rigor that has always characterized it has remained a constant.

During incredible days of intense activity inside the ISS in orbit at a speed of 28,000 km/h around our planet, you are not aware of all the work that has gone into those times. However, you only have to reflect for an instant to understand how much of what only a few people have the privilege of experiencing is the result of the work of thousands of men and women who for years have planned, realized, and managed a network of programs and projects to make the largest house in space.

The subject of space program management, especially where the human factor figures, is therefore so complex and varied that even an astronaut (the very person who incarnates the essence of the reason men and women design spacecraft or orbiting stations) is unaware of the whole picture.

This is why reading a book which examines several of the vital mechanisms of the three sides of "technological-management-financial development" helps us to better understand how this fascinating and complex world works, a world where a few hundred space objects in orbit around the Earth help us every day to understand the climate, to communicate with each other, to locate, and help us to live in space to explore and experiment new ways of propelling human life beyond the frontiers of the Earth itself.

We now have the “experience” of how to live in space, thanks to planning and management logic that was completely unknown until a few decades ago. The inductive principle has become essential for extrapolating general rules from the individual cases of prior experiences in order to create standards of reference for new and innovative programs that drive man ever further into the universe.

In this sense, I consider it a duty to thank the author of this book. He is a personal friend of mine whose clarity of thought and ability to analyze and synthesize have translated into the passion evident in this book.

A passion, which is for us all and for the future generation of scientists, engineers, astronauts, and human beings in general, the source of curiosity and knowledge.

Pilot of the Italian Air Force
Astronaut of the European Space Agency ESA

Roberto Vittori

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- Mr. Mauro Balduccini wrote Chap. 6.
- Mr. Federico Nasini wrote Chap. 7.
- Mr. Richard Fleeter wrote Chap. 8, and extensively revised the whole book.
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- Mr. David J. Goldstein wrote Sect. 9.2 of Chap. 9.
- Mrs. Pat Remias wrote Sect. 9.3 of Chap. 9.

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A special thank to Margaret Lombardi for her valuable help in translating the text in English.

All the authors and contributors declare that the topics discussed in this book are based entirely on personal experience and in no way involve the agencies or companies where they are employed.

Contents

Introduction

Space missions are one of humankind's activities in which the ambitious goals achieved—the putting into orbit of the first satellite, human spaceflight, application programs for telecommunications and remote sensing, the Moon landing, the assembly of the great orbiting space station—have had to co-exist with the development of technologies, the challenges of innovation and research, available resources, organizational competences, the ability to manage risks and costs and to maintain time schedules with the expected margins.

This difficult synthesis of ambition and realization, vision and real workability have characterized all the greatest undertakings, in all fields of human endeavor, and regardless of the motivations of an economic, social, military, scientific, humanitarian, or cultural nature which prompted them, the factors which characterize great undertakings and which make them viable are recurrent elements.

Space activities, however, embody the measure of great human missions more than any other and still strike our imagination, while they are here with us on a daily basis. All we have to do is think of the great International Space Station to have immediate confirmation of the feasibility and concreteness of a success that seems to reaffirm itself each day.

Marcello Spagnulo, the author of this book on space programs, offers to the reader a complete overview of the factors which make up a space mission, an activity which, just like all great undertakings, has always been very complex, rich with challenges and risks, time schedules and considerable costs which are often very uncertain.

The book richly details and expresses the specific nature of the space sector starting with an overview of these developments in various countries. It illustrates historical developments at length and the outlook of the space market. In this way the author more or less implicitly defines the reasons for which man decided to propel himself into space and the objectives of the space missions that were carried out.

One chapter is dedicated to program management, an activity in which the author, because of his experience in his rich and varied career, has acquired his expertise directly. The description of management proposed in this book therefore enriches a systematic description of this subject with the vision of experience. Program management is the first of the major factors necessary for developing every great mission, especially space programs. The book examines its essential aspects, dedicating great detail to specific areas, such as the management of configuration (of great importance also in the related field of aeronautics) and the management of delays, an issue that is of strong current interest to all complex industrial programs.

Space missions carry high levels of risk. The book pays particular attention in detailing technical and financial "reliability and security" issues and the insurance market for space programs.

The management of costs and financial issues brings the book to a close with two chapters devoted to subjects which are usually ignored in space education courses, but

which are of increasing importance for future space programs. Cost is an increasingly critical factor in missions and in the development, implementation, and management of space systems. This criticality, linked to various factors but relevant both for space industries funded by government agencies and for space companies working in the market, has transformed cost from a factor of program management to a factor in mission planning.

Paradoxically, financial issues will bring about more innovation. The future of many space industries in the development phase will be linked to the ability to implement financing that involves public–private types of partnership for developing and implementing programs.

It is a well-organized and complete book, and not difficult to read, even for readers who have not come across space issues during their university studies or professional experience.

This is an important feature for a book on space programs. In fact, in as much as technology and science certainly play a determining role for the implementation and success of every space mission, space is not just a world of engineers and scientists. The professions involved in each space program cover a very broad spectrum ranging from economics to management, legal issues to financial ones, political to military and security issues, and life sciences to medicine.

Marcello Spagnulo's book provides the world of users, who only encounter the space world at a certain point of their career, with an instrument for understanding the world of space programs and for an in-depth examination of the various issues.

Because of its organization, complexity, and completeness, the book can also be used as a tool for an in-depth study of the themes examined to benefit technical experts—scientists and engineers—who because of their involvement in a problem, can sometimes lose sight of the overall picture when they encounter elements outside the technological realm.

Marcello Spagnulo's involvement in the educational community of the Master's program in satellites and orbiting platforms of the University of Rome "La Sapienza" (where he obtained his degree in Aeronautical Engineering) is related to his desire and effort to conceive and realize such a rich and complete book.

During my teaching experience and in defining the scope and didactic contents of the Master's degree in satellites, I had the good fortune to meet many professionals, such as the author of this book, who wanted to pass on their experience to new generations and to other professionals who wanted to update their professional abilities and enter the world of space. As is well known, the University of Rome "la Sapienza" was the cradle of Italian space activities and it is perhaps for this reason that an operational and application component has always been present in our cultural tradition alongside academics and research.

Today this tradition allows us to develop research and development programs in various space venues in intense synergy with the world of space agencies, companies, and institutions that are involved in space in various ways. High-level training in space systems and missions put the academic community in close contact with various organizations that develop and operate space programs.

For these courses, Marcello Spagnulo's book will be a precious tool in the years to come for the cultural and professional development of those who wish to become involved in space missions of the future.

Paolo Gaudenzi
Full Professor of "Aerospace systems and design" at the University of Rome "La Sapienza"
Director of the Master's program in Satellites and Orbiting Platforms and Coordinator of the Research Doctorate in Aeronautic and Space Technologies

Introduction by the Author

When I published in 2011 the Italian version of this book I choose as cover a photo from NASA website which always has been in my mind as an icon.

The image I'm talking about was taken on 21 July 1969 from the porthole of the command module "Columbia" of Apollo 11. It shows the lunar module "Eagle" which stands out from the surface of the moon after having landed on it only 24 h earlier. On board the lunar module are the first of two human beings who landed on a celestial body outside of Earth for the first time in history. And in the dark background of the photo, just behind the lunar module, a bright tiny Earth is suspended in space.

The Apollo 11 mission, through this iconic photo, represents, in my opinion, the most striking image depicting a small machine built by man which travelled in a sidereal void from Moon to Earth. It signaled a high point, a peak that till today has not been scaled again by the scientific and industrial community involved in the difficult task of sending human beings or probes into orbit around the Earth or into deep space.

But the entire Apollo program was a watershed. This was not only because of its technological, political, and scientific success, but also because of its value as a conceptual and project reference.

In order to have a million pieces that made up the Apollo spacecraft function perfectly 380,000 km away from Earth, the US space agency NASA, together with industries and universities involved in the lunar program, conceived of rules and procedures that have influenced project and management modalities for all subsequent space programs.

This is why a book which attempts to illustrate several general management principles of space program management cannot help but give due credit to this human mission which continues to leave its mark on activities that see men and women in Europe, as well as in the USA, Russia, Japan, India, China, Canada, and other countries still involved in the planning and building of satellites and spacecraft.

But there is an even more personal reason for having chosen this photo as a symbolic icon.

For every engineer, who like myself, studies the basics of Astrodynamics to learn how to face the fascinating intellectual and technological challenges of our profession, one of the basic texts was the book "Fundamentals of Astrodynamics" written in 1971 by three professors, Roger Bate, Donald Mueller, and Jerry White, who worked in the Department of Astronautics of the US Air Force Academy.

This book had that same photo on its cover.

I had a copy of the book in 1981 by an engineer at NASA's Goddard Space Center, whom I will never cease to thank for his part in helping me understand our world a little better.

Rome, January 25th 2011 Marcello Spagnulo

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Chapter 1

Space Activities: A Peculiar Economical, Political, and Industrial Sector

In the twentieth century, man on the mechanical wings of technological and industrial progress conquered the frontiers of air and space. Space relatively near the Earth's surface, between 12,000 m altitude from Earth, has become a polluted area of traffic and life because of the increase in air transport. Only a few hundred men and women have crossed outer space, beyond 100 km, in the last 50 years.

The mechanical wings on which these men and women have flown outside the Earth's atmosphere are called space launchers. They are sophisticated missiles with capsules and passenger compartments on board which protect human beings from deadly extra-atmospheric conditions.

The history of missiles in the last 50 years of the twentieth century therefore coincides with the history of the development of human space programs—astronautics.

Because of space's lethal conditions outside the Earth's atmosphere, man has planned and sent robots into space. These probes or satellites have electronic equipment that can receive and transmit data, take photos while flying around the Earth, or that can land, for example, on Mars, or travel to deeper space.

Therefore, we cannot really say that we have finally "conquered" space, a term that in our opinion is often used incorrectly to emphasize the truly important achievements of man, filled with fascination due to their complexity and to the prevailing unknown.

Truthfully, the strategic and military implications of human activity in space, both with astronauts and satellite or probe launch, were quickly understood and utilized by the military institutions of the most powerful countries on Earth, particularly by the two that were to become the winners of the Second World War, the USA and the former Soviet Union, the USSR.

A history of space missiles and astronautics must review the scientific and industrial events of these two countries.

However, ever since the 1970s, other countries including Europe have slowly undertaken space activities with greater strength and efficiency. The evolution of this sector is constantly changing because emerging continents, China and India first, have now developed industrial capability in several cases superior to Europe.

Today a real governance of space has developed. It is a collection of organizations and rules that have been created by industrialized nations to develop and manage space programs.

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Of course, each nation has developed and is developing according to historical and political advancements, its own space governance. The challenges of the future are also being met with more global instruments, though critical and difficult to achieve, in order to have governance evolve in this sector.

1.1. Brief History of the First Space Age

The first space programs were begun at the end of the Second World War in rocket science and were conducted by the two winning powers, the USA and Russia, who appropriated German scientists and their technological knowledge.

The Germans had started up important technological developments during the war in rocket science to the point where they built missiles, the V-2, which could reach 80 km in altitude at a speed of over 5,000 km/h, for all purposes the first missiles built by man that could reach outer space.

The Russians began their space journey with military programs and objectives and worked without revealing the progress of their developments.

The USA first had small, rather conflicting programs because of the rivalry between various branches of the armed forces that had understood the potential for the use of space from the beginning. However, their work, which from the very beginning had a public nature that was ostensibly scientific, carried out openly, and so its advancement was easier to follow.

The initial public objectives of the space programs were linked to Earth science and the exploration of the upper atmosphere. In preparation for the "International Geophysics Year" in 1957, the USA announced its "Vanguard" project for launching small capsules containing special electronic devices for measuring the physical phenomena of the upper atmosphere into space using missiles. The mission's objective was to have the capsules orbit around the Earth, creating small satellites like the Moon, although artificial ones.

The Russians made the same announcement and amazed the world when they succeeded in putting into orbit the first artificial satellite, the Sputnik 1 with an R-7 rocket launched from the Baikonur space base in Kazakhstan on 4 October 1957 before the USA.

It was only on 31 January 1958 after the dramatic failure of the Vanguard launcher that the Americans succeeded in the first launch of the Jupiter missile designed by German Werner Von Braun, who had been the head of the V-2 program during the war.

Thus began a series of satellite launches that became more and more technically complex between the two world powers.

It was also the Russians who overcame the Earth's orbit: on 2 January 1959, Lunik 1 almost touched the Moon, and then on 12 September 1959 Lunik 2 fell directly on the Moon's surface. Finally, on 4 October 1959 Lunik 3 went on an orbit that circled the Moon and took photos of its hidden side that had been unknown to man until then.

There were numerous satellite launches. The most memorable include Pioneer V launched in solar orbit and the Sputnik V, which put two dogs into orbit who were recovered alive on ground, then the Venusik that flew 100,000 km over Venus.

Figure 1.1. Yuri Gagarin's takeoff from Baikonur on 12 April 1961. (Roscomos RKA web site source).

It was then man's turn into space and on 12 April 1961 Russian cosmonaut Yuri Gagarin was the first man in space with the Vostok I capsule, placed atop the Semiorka launcher built by the father of Russian astronaut Serghej Korolev. Gagarin's undertaking was brief but intense. After an orbit of 108 min around the Earth, he returned unharmed (Figure 1.1).

On 6 August, German Titov, on board the Vostok II, made 17 orbits in about 25 h.

Russia's space success brought about a radical change in the USA's way of thinking and attitude because it became a matter of national pride and because it became imperative to recover lost time from a military and scientific point of view.

The frenetic race to develop launchers became intense and when the Redstone missile and the Mercury habitable modules were ready, the USA sent their first men into space, the "Magnificent Seven" who were defined as astronauts drawn from the ranks of test and military pilots.

On 5 May 1961, Alan Shepard made a suborbital flight followed by John Glenn on 20 February 1961 with the first real orbital flight, followed by Scott Carpenter on 24 May of the same year, and so on, all the others.

However, it was the Russians who once again accomplished a space "first" in August 1962, launching a large capsule with astronaut Nikolaiev on board and after 2 h a second one with astronaut Popovic. The two capsules traveled for 3 days at a minimum distance of 5 km and had radio contact. These astronauts returned to Earth safe and sound after having spent over 4 days in space.

The President of the USA, John F. Kennedy, in his 1961 State of the Union address announced that the Americans would start a space program for having man land on the Moon by the end of the 1960s and to have him reenter safe and sound to Earth.

Figure 1.2. The Earth photographed for the first time from the Moon by the astronauts of Apollo 8 during Christmas 1968. (NASA source).

The enormous technological and industrial effort of the Americans focused itself from that moment on the Moon mission.

The decision to direct all of its efforts to the lunar space program was taken by the USA when it was under shock from Soviet space supremacy and was undergoing serious military crises such as Cuba and Vietnam.

Thus, the Americans wanted to recover their prestige as the absolute first world power in the public's opinion and therefore aimed at the Apollo Moon program to reposition themselves politically and strategically with the Russians to increase the nationalistic spirit of its citizens with a new American dream (Figure 1.2).

In 1964, the Russian capsule Voskhod I guided by Colonel Vladimir Komarov and with K. Feoktistov and medical doctor Boris Yegorov was successfully launched. Voskhod I was followed by Voskhod II, launched on 18 March 1965 and on 24 March, the Americans launched their first guided two-seat spacecraft, the Gemini, with Virgil Grissom and John Young on board. Its objective was to clear the way for exploring the Moon.

The Titan II launcher had to be developed. It was much more powerful than the Redstone and allowed the USA to fly the Gemini capsule.

On the American side, nine other Gemini program flights followed to acquire better knowledge on the "rendezvous" maneuvers to be done in space on much more difficult missions such as those of the future Apollo spacecraft.

The series of flights of the Gemini program ended in November 1966, while Von Braun and his team at the NASA center in Huntsville, Alabama completed the building

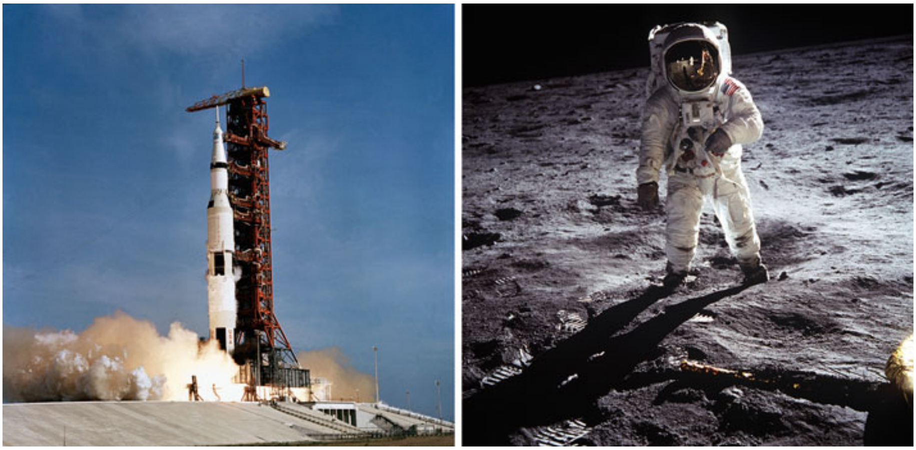


Figure 1.3. Two scenes from the Apollo 11 mission: takeoff on 16 July 1969 and the Moon landing on 20 July. (NASA source).

of the giant Saturn launcher with the objective of reaching the Moon with the Apollo spacecraft.

World public opinion was informed, often in a spectacular fashion, only of civil space missions and especially of the probes sent to the Moon, Mars, and Venus, both by Russians and Americans.

Then the Apollo space program entered into the heart of their successes between the end of 1968 and the middle of 1969, with the flights of Apollo 7 and Apollo 10. The most important testing for preparing the Moon landing which occurred on 20 July 1969 with the Apollo 11 mission was completed with flying colors.

The whole world followed the Moon landing phases on live television broadcast when Neil Armstrong cautiously put his foot on Moon soil saying these words: “That’s one small step for man, but one giant step for mankind.”

Armstrong was accompanied by Edwin Aldrin who landed on the Moon with him on board the LEM spacecraft, while Michael Collins remained in the Apollo capsule in lunar orbit (Figure 1.3).

One after another, the Moon landings followed at approximately two per year until NASA decided to stop the Apollo missions in 1972 because of budgetary reasons and progressive disinterest by the public for these types of missions. In total, nine American missions toward the Moon were carried out with 24 astronauts, the only ones to have left the Earth’s orbit until today. Only 12 out of these 24 astronauts landed on the Moon.

The Apollo 13 mission aroused strong emotions because it almost risked turning into tragedy when halfway between the Earth and the Moon an explosion on the spacecraft drastically cut off the available oxygen and energy. The LEM lunar landing module was used as a lifeboat and its motor worked to bring the worn-out crew back from an odyssey whose reality surpassed science fiction films.

During the 1970s, the Russians and Americans cooperated in space missions on board their respective orbiting stations around the Earth, the Mir and the Skylab, but

the most interesting space programs were not the ones with astronauts but those of interplanetary probes that revealed the secrets of Jupiter, Saturn, and the most distant planets.

At the same time, space industry began to develop recurrence satellites for military and civil communication applications more often, especially for telephones and television, Earth observation, weather and monitoring, and so global industries, in the USA, the Soviet Union, and Europe were set up to build larger and more efficient satellites.

In 1969, the American company Bell Telephone Laboratories announced that they had made the first telephone call via a man-made satellite.

The satellite was named "Echo" and it was nothing more than a giant 30 m in diameter sphere made of aluminum-covered plastic, in orbit at about 1,600 km altitude. On 12 August 1960, a signal sent from Goldstone, California, after bouncing off Echo's surface, was received by Bell Laboratories at Holmdel, New Jersey on the opposite coast of the USA. The signal, transmitted on microwave band, was a prerecorded message by President Eisenhower. It was the first demonstration of the possibility of radio communication on a global scale.

However, the orbits such as Echo's were not suited to permanent communications, so the idea that appeared in 1945 in an article in the scientific magazine "Wireless World" made its way. The author, Arthur C. Clarke, demonstrated, without thinking in the least about the revolutionary implications of his thesis, that a satellite positioned in equatorial circular orbit at an altitude of 35,786 km from Earth does a complete revolution every 24 h and an observer on the Earth's surface could always see a geostationary satellite in the same position in the sky.

Clarke also proved that a few satellites in geostationary orbit were enough to offer communications services to the entire world.

Twenty years were to pass from the publication of this article before the first geostationary satellite for telecommunications (telephone services), Early Bird, was launched for Intelsat, the "International Telecommunications Satellite Organization," in April 1965.

From that date until today, hundreds of geostationary satellites that cover all the continents of the world have been put into orbit.

In Europe, the European Space Agency, ESA, created in 1975, developed the OTS Telecommunication satellites that were later supplied to the Eutelsat organization based in Paris (Intelsat on a European level), and the MeteoSat satellites for weather observation that were also later transferred to a specially created European organization, EumetSat, for managing the fleet of satellites and related services.

This growing industrial capability created another commercial sector, which by using the spin-offs of military and scientific use, introduced initiatives into the private business market linked mostly to telephones and television. This market contributed to the growth of a launch services market, which are the sales of space transport services for satellites.

Going back to the 1971–1981 decade, the Americans, after the Apollo space program, started up and realized the Space Shuttle program, which revolutionized the concept of space transport, aiming at flying an airplane-like spacecraft, which was almost completely reusable.

Figure 1.4. 8 July 2011: the Space Shuttle Atlantis takes off for the last mission of the spacecraft after 30 years. (NASA source).

In 1981, the Shuttle successfully began its flights, while the Russians progressively abandoned the development of spacecraft because of economic restrictions due to the growing social-economic decline of the Soviet communist regime. At the end of the 1980s, the USA appeared to be the winner of the space race, equipped with a Space Shuttle fleet that took off and landed from Cape Kennedy, while Russia always used its launchers derived from its first missile Semiorka. Other nations, including European ones, began to open up with increasing boldness to space launcher missions.

However, the disasters of the Space Shuttle, the Challenger in 1986 and the Columbia in 2003, had a dramatic impact on American and international space activities since the Shuttle flights depended on the still ongoing construction of the International Space Station (ISS) designed by NASA in cooperation with the European, Japanese, Russian, and Canadian agencies (Figure 1.4).

The ISS, conceived in the 1980s, began to be assembled in orbit in 1998 and the first astronauts entered it on 2 November 2000. The ISS, today completed and inhabited permanently by six astronauts, orbits at 360 km altitude and is reached by the Space Shuttles and also be the Russian Soyuz, launched from Baikonur.

The Columbia accident in 2003 further weakened faith in the Space Shuttle that was terminated in 2011 with the STS-135 mission. Therefore the Russian Soyuz will be the only transport for going into space while the world waits for a new American spacecraft.

At the moment the ISS is the only large space infrastructure that is the result of an international cooperation.

Even space missions for scientific research have been a sector of great international cooperation. Initially in the 1960s and 1970s, the automatic probe scientific mission was the exclusive prerogative of Russia and the USA, but in the 1980s even Europe, Japan, India, and China developed scientific missions of outstanding interest and results.

The planets of the Solar System were visited by many probes such as the Voyagers and the Cassini-Huygens spacecraft, the result of an important cooperation between the USA and Europe. Three American rovers have made long journeys to the planet Mars' surface. ESA has sent a probe to the nucleus of Halley's Comet, created a capsule that landed on Titan, a Saturn moon, and in 2009 put into orbit two satellites, Herschel and Planck, which are producing a vast array of data on the deep and unknown universe.

The Hubble space telescope, put into orbit and repaired many times in space by the Space Shuttle crews, has supplied outstanding images of the Milky Way and deep space for almost 20 years.

Thanks to satellites and space probes, the images of the planets, galaxies, and wonders of the cosmos have now become familiar in all school textbooks and popular magazines.

1.2. Brief History of the Space Activities in Europe

In the mid-1960s, the Soviet Union and the USA had already sent satellites and men into space and were competing to conquer the Moon.

The European countries were convinced that they had to develop their own space program, to consolidate the new and fragile European political entity whose self-imposed mandate at the end of the Second World War was to integrate its own industrial and technological capabilities. It was also quite clear that no space program could be conceived without a reliable launcher system and an operational space base.

In truth, in Europe the two winning powers of the Second World War, France and England, had already begun developing space launcher technology already beginning in the 1950s, but with a radically different approach. The English were supported from the beginning by American technologies to develop ballistic missiles, the Bluestreak, capable of transporting atomic bombs which could at the same time be transformed into space launchers. The English used the Woomera base in Australia for operations and from the beginning of the 1960s had developed an advanced program for the management of launcher operations. England was in fact the fourth nation in the world to put a satellite into orbit, after Russia, the USA, and Italy.

In 1964, Italy had built and launched a true technological jewel, the San Marco, from the American Wallops Island base. It then adapted a petroleum platform in Kenya in 1967 for use as a launch base. Italy had begun the development of technologies for building satellites, but it had not developed technologies in the launcher sector since it was thought it was more economical and reliable to buy launches directly from the Americans instead of investing in developing them.

After a few years, toward the end of the 1960s, even the English decided like the Italians and determined politically it was more economical to rely on the launch of English satellites to US launchers, instead of continuing to invest heavy sums on this technology.

Instead, the French decided right from the beginning to aim at the development of their own launcher technologies. They even made rocket science one of their cardinal points of their "Force de Frappe" policy, which was strongly favored by General De Gaulle, president of the French republic.

The "Force de Frappe" was France's autonomous capability to defend its own territory and attack the outside with nuclear capability. In order to do so, it had to have jet airplanes, ships, submarines, and missiles. It was a short step from missiles to space launchers.

President De Gaulle did not fail to notice the strong military value of space. In 1961, he created the Centre National des Etudes Spatiales, CNES, which is to date the national French agency for space activities. He called upon a general of aviation to head the agency.

CNES focused on studying and developing satellites and "Diamant" launchers. The "Diamant" was a three-stage launcher that successfully completed 10 out of 12 launches from 1965 to 1975 and allowed France to put 11 satellites into orbit.

France became the fifth country in the world to launch a satellite into space, but was the only one after Russia and the USA to have done it with its own technologies and not acquired ones, even partially, from overseas.

When France created CNES, European community organizations undertook plans for a common research in space programs, so in 2 years a restricted number of European companies created two space agencies, ESRO, *"European Space Research Organisation*," and ELDO "*European Launcher Development Organisation.*"

ESRO was to promote the study of space by developing satellites, while ELDO, created in March 1962, was to concern itself with developing an autonomous launch system.

The turning point was reached in 1975 with the creation of the ESA in which the two organizations, ELDO and ESRO, merged (Figure 1.5).

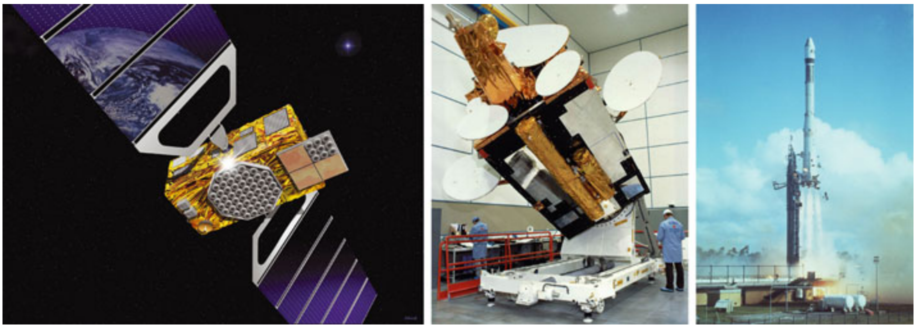


Figure 1.5. Past and future of the European Space Agency: from right to left the takeoff in 1979 of the first Ariane launcher, the satellite Olympus for telecommunications, and, to the right, the future Galileo satellite. (ESA source).

An improved organization and the homogeneous use of resources brought the first encouraging results for launchers and satellites. Thus the Ariane programs for the launch vehicle, MeteoSat for meteorology, OTS for telecommunications, as well as a certain number of scientific probes were developed. The foundation for modern space missions was cast.

1.3. Brief History of the Space Activities in the Rest of the World

Space technology development in the 1960s and 1970s has also allowed the nations of China, India, and Japan to move into the world of high-rank space faring countries, a place previously occupied only by the USA and Russia.

India launched its first satellite Rohini 1 on July 1980 onboard a full indigenous SLV rocket from the Sriharikota Island launch site. In the following years, India concentrated its space effort on telecommunications and earth observation satellites as well as on powerful rockets, becoming fully independent in all these technologies. Also an Indian cosmonaut Rakesh Sharma spent 8 days in 1984 aboard the USSR's space station Salyut 7, but for the time being a manned program is not going to be soon developed.

The China Space program has a well-known "father": Tsien Hsue-Shen, who studied at the MIT with rocket scientist Theodor Von Karman, then continued his studies at the CalTech, finally contributing to found the Jet Propulsion Laboratory in Pasadena. When the USA and China entered in the 1950s into a period of confrontation after the collapse of the US-backed regime of Chiang Kai-Shek and the victory of the Communist Party in China, Tsien Hsue-Shen became victim of the anticommunist policy within the USA, and was deported to China. There he was welcomed as a hero and immediately started the China's space program, making enormous advances in the 1970s and 1980s. The first Chinese satellite was launched in the mid-1970s and in the 1990s China launched Asiasat-I, an advanced telecommunications satellite comparable to the western made products. The CZ-2 launch vehicles class allowed the production of big and powerful rockets capable also of launching the manned spacecraft Shenzou, which was finally put in orbit in 1999. In 2003 the first Chinese astronaut went into orbit onboard a Shenzou 5 spaceship atop of the enormous CZ-2F launcher, making the space manned program a reality. In 2011, the first modules of the Chinese space station, expected to be completed by 2020, were launched successfully.

The Japanese space program started in 1955 at the University of Tokyo, where the Institute of Industrial Science began work with sounding rockets. In 1964 the Institute of Space and Aeronautical Science (ISAS) was founded at the University of Tokyo, but in the 1960s all satellite launches failed.

In 1969, the National Space Development Agency of Japan (NASDA) was established to take the lead in the development of space capabilities, including satellites for remote sensing, meteorology, and telecommunications, as well as launch vehicles and facilities for producing and tracking the satellites. Also in 1969, Japan and the USA signed an agreement allowing the transfer of unclassified space technology from US firms to Japan. The terms of the agreement prohibited reexporting of the technology by Japan, precluding effectively Japan from commercial

marketing on the international market for launch services and communication satellites. But at a final end the agreement permitted to Japan to develop system capabilities for design and production of satellites and launchers. After this move in 1970, the first Japanese satellite was successfully launched into orbit. In 2003, ISAS, National Aerospace Laboratory of Japan (NAL), and NASDA were merged into one independent administrative institution: the Japan Aerospace Exploration Agency (JAXA). The consolidation of these three formerly independent organizations allowed the synergy among the various space programs which since the 1960s those entities were pursuing separately. In the 1990s and beginning of 2000, the Japanese space program underwent a crisis of confidence following a succession of satellite and launcher failures. But since then the space program was deeply reorganized, and a new renaissance took shape allowing great success in the scientific programs on the moon and on asteroids, as well as in the application satellites, launchers, and manned programs within the ISS framework. Also Japan launched in 2000s its first military/intelligence reconnaissance satellites becoming a true space faring nation.

1.4. The “Governance” of the Activities in Space

By space “governance,” we mean the political, military, and economical decision-making factors that can influence scientific research and industrial development for space activities in the framework of a nation.

“Governance” is therefore a guiding and management tool in space activities and is clearly the prerogative of those nations in the world that have developed those capabilities, that is the USA, Russia, Europe, China, India, and Japan and in a very minor way, Israel and Brazil.

Space, defined as the exo-atmospheric environment near the Earth, is a strategic element, but it is also of commercial interest. In countries that have developed industrial capabilities of access and use of space, governance is therefore an instrument aimed at political–industrial objectives inside and outside the country.

In space, satellites fly over the globe without territorial limits. Therefore, space activities can be a significant instrument for enhancing a country’s foreign policy. It is easy to see how the strategic aspect of space is intrinsically related to the concept of security and defense since militarily it represents the fourth level, after marine, ground, and air, of the armed forces field of operations and its use for these purposes seem to be gaining increasing support.

The militarization of space, which is the deployment in orbit of active offense systems, does not yet exist, but we should not ignore the signs of progress in Chinese technology and obviously American technology in this field, for example, the interception and destruction of an orbiting satellite.

Therefore, it is clear that in order for space activities to be effective they must be complete, affording the ability to make spacecraft, satellites or probes, and transport vehicles, such as launchers, to support the nation on a global political level. Considering the two vehicles as separate space systems and not necessarily both developable within a country or continent could be a serious political, strategic, and economical error.

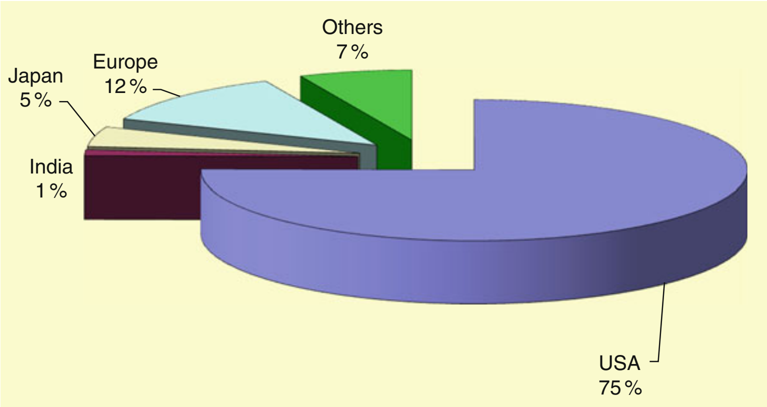


Figure 1.6. Geographic estimated distribution of expenses, civil and military, for the space sector in the world. (Finmeccanica SpA elaboration source).

"Governance" is basically of an internal and foreign political nature. It is managed to generate economic and industrial returns to justify the high government investments required and to guarantee only a part of self-financing with commercial activities. Economic data of the last 20 years have shown that the commercial part of the sector is a form of complementary financing which only integrates and accompanies governmental funding in several application fields.

Nevertheless, autonomous and independent industrial capability in satellites and launchers is a very important element for a country or continent that aims at affirming itself politically and strategically on the international scene.

To quantify world space governance, that is, the comparison of the finance capability of various nations, we can examine several significant numerical data.

Figure 1.6 illustrates for example the estimation of the percentage of civilian and military investment in the world for countries with space capabilities. We can infer that the USA spends over 70% of what is invested globally in the sector, but we must also consider that Russia, India, and China have an intrinsic "technological value" far superior to the figures reported which come from not always official sources.

According to estimates of Euroconsult in 2010, world public spending was around 72 billion dollars, of which 12 billion dollars for human spaceflight, 8.4 billion dollars for telecommunications, 8 billion for Earth observation, 6 billion for space science, 5 billion for launchers, 3 billion for radio-navigation, and 2 billion for security systems in space.

These are impressive data that however diminish the lack of transparency of the US military programs, which is also the case in other countries where investments are not clear.

Figure 1.7 shows an estimated comparison between the progression of investments in the USA and in Europe for civil and military space activities, highlighting the well-known difference.

In Figure 1.8, the estimated funding for the space sector as a percentage of Gross Domestic Product for the three industrialized continents based on the economy market is indicated.

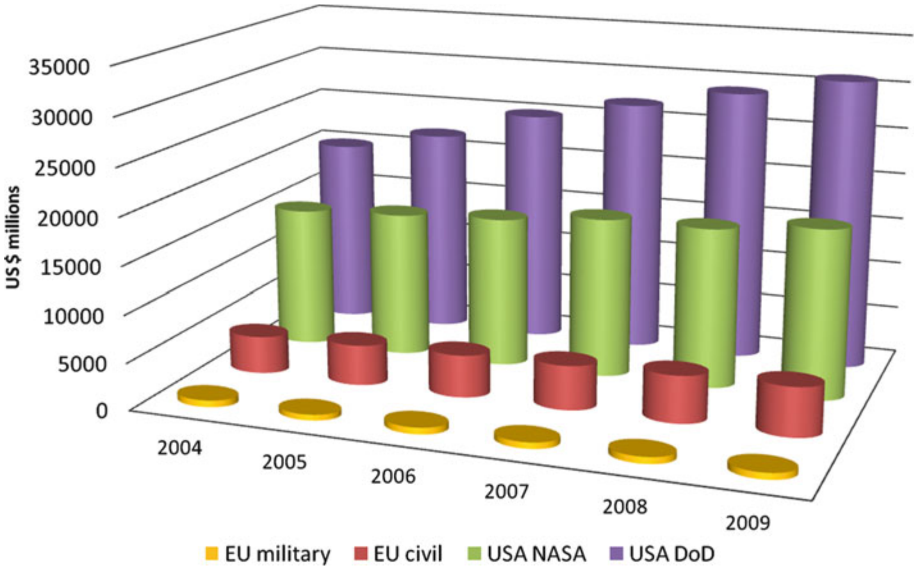


Figure 1.7. Estimated progression of civil and military costs in the space sector in the USA and Europe. (Finmeccanica SpA elaboration source).

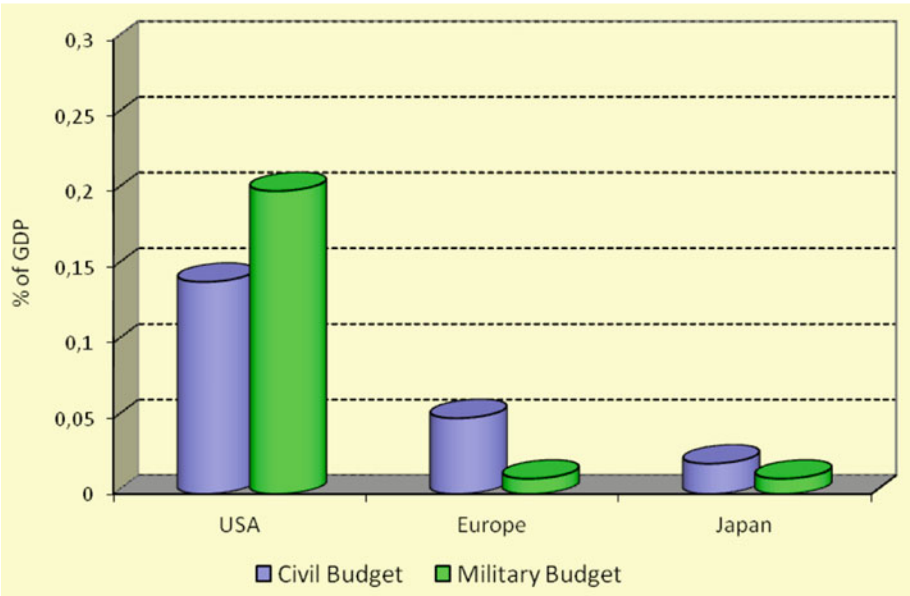


Figure 1.8. Estimated percentage of gross domestic product on space civil, and military costs in the USA, Japan, and Europe. (Finmeccanica SpA elaboration source).

	Human and Financial Resources devoted to space activities	Predominance of the role of Public Institutions on the *Governance* of the space activities			
		Government	Parliament	Armed Forces	Space Agency
USA	• • • •	• • • •	• •	• • • •	• •
RUSSIA	• •	• • • •	•	• • • •	• •
CHINA	• • • •	• • • •	•	• • • •	• •
JAPAN	• • •	• • • •	• • • •	• •	• • •
EUROPEAN SPACE AGENCY	• • •	• • • •	not applicable	not applicable	• • • •
FRANCE	• • •	• • • •	• •	• • •	• • •
INDIA	• • •	• • • •	• •	• • •	• •
GERMANY	• • •	• • • •	• • • •	• •	• •
ITALY	• •	• •	•	• •	• • •
ISRAEL	• •	• • • •	• •	• • • •	• •

• Low • • • • High

Figure 1.9. Qualitative analysis of space *Governance* worldwide.

It is somehow difficult to analyze those data without considering the strong unknowns related to the lack of information on the budget of various entities or nations. For instance, it is truly unknown the real level of investment on space activities of the US Department of State as well as of the US Intelligence Offices which heavily rely on space systems. Also level of expenditure in countries such as Russia or China are not known, nor declared, and it is nearly impossible to derive those data by comparison with western standards such as the labor force cost.

Thus a qualitative analysis of the "Governance" of the worldwide countries possessing space assets capability and technology can be synthesized in Figure 1.9, where general considerations are reported to provide a brief assessment of the various typologies of space *Governance*.

The management of these expense and investment capabilities is expressed in the nations of the world through a governance of the sector that is then briefly examined with regard to those countries with significant technologies.

The United States of America

In the USA, the space sector represents a very flexible institutional scenario but the strategic guideline is given by the President. Many civil and military organizations then have the authority and budget to develop and operate space systems.

Figure 1.10 illustrates schematically the institutional scenario of the USA, highlighting the main organizations involved in space activities.

The President expresses the guidelines on space strategy through three main documents, the "National Security Strategy," the "Presidential Decisions Directives" (e.g., the National Space Policy), and the "Presidential Review Directives." The President can even influence national policy in the sector, by applying his own executive power and directly appointing the heads of the principal institutions active in the sector, as for example NASA's administrator, the civil American space agency.

The other instrument available to the President to influence the guidelines for national space policy is the annual expense budget prepared by the Office of Management and Budget (OMB) which has powers of evaluation and control on the operations of the main agencies.

The President is directly assisted by various consulting organizations, including the "National Security Council" for all matters regarding security of the country, the "National Science and Technology Council," and the "Office of Science and Technology Policy" to improve the coordination of efforts at the federal level in science and technological development.

The federal government of the USA invests over 30 billion dollars in the space sector each year in known civilian programs. The true military expense, which has grown constantly over the years, is not known.

Figure 1.11 schematically illustrates an estimate of the level of financial resources that are known to have been used by the USA during the period 2006–2009.

The main military and intelligence institutions that realize space systems based on military space policy guidelines given by the President are the CIA, the Department of Defense DoD, and the National Reconnaissance Office NRO.

At the operative level, the main military institutions in the sector are the "US Space and Missile Strategic Command" which develop the main military programs for space, and the "US SPACECOM" which manages military satellites.

The "National Space and Aeronautics Administration" NASA is the main and most well-known space agency in the world and is involved in the research and development of civil space activities.

NASA runs ten centers in the USA, as shown in Figure 1.12, and is active in science, aeronautics research, space operations (that is the Shuttle flights until 2011 and Space Station), and exploration.

NASA, almost 40 years after the Apollo Moon missions, had begun an ambitious program of space exploration in 2004 with the aim of having a crew land on Mars by 2050.

Figure 1.13 illustrates, as an example, the overall planning of this exploration project called "Constellation" in which NASA, from 2004 to 2009, had invested almost nine billion dollars. Then in 2010, "Constellation" was essentially cancelled by the present administration of President Obama and currently the USA is still in the difficult phase of redefining its own space programs. The new Global Exploration Roadmap is expected during the second half of 2011 or most likely during 2012.

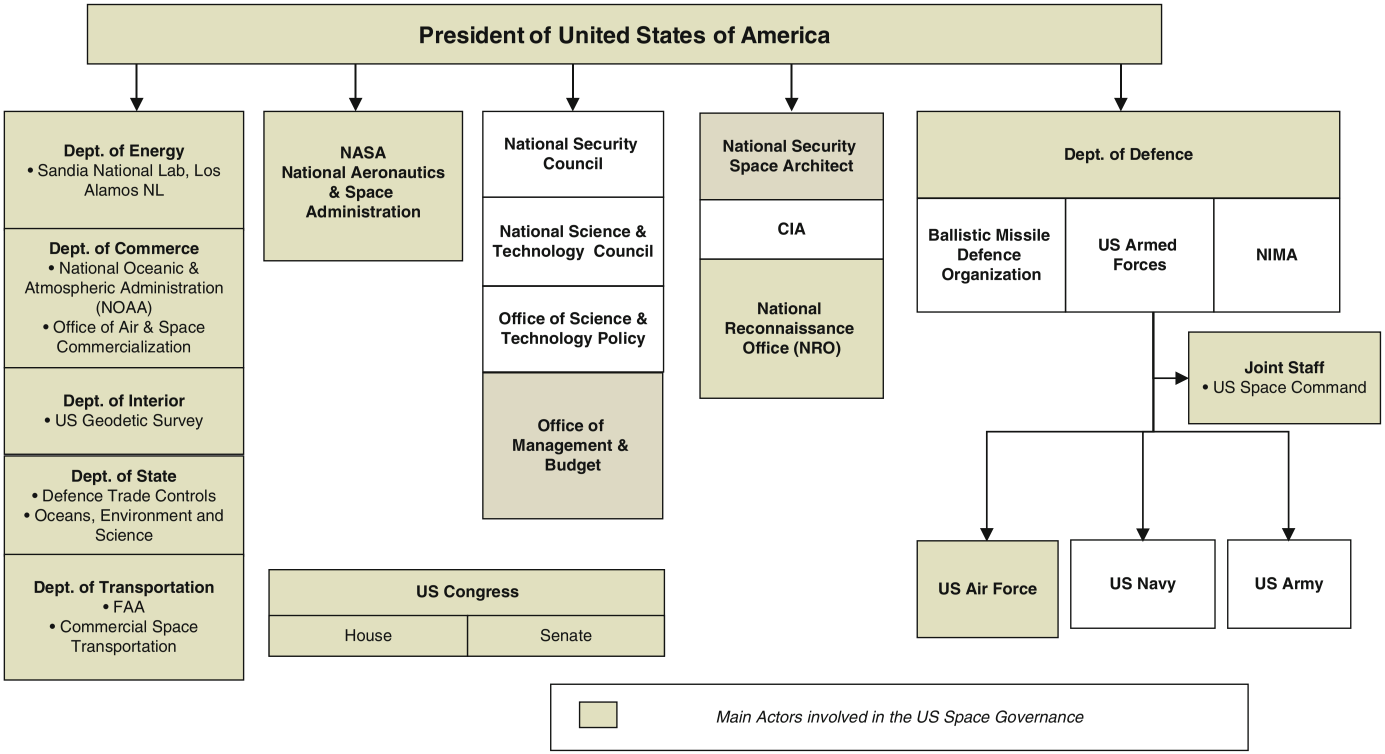


Figure 1.10. US Institutional Scenario concerning the space sector. (Jane's online source, US Space Commission public release report source, Press release source, Finmeccanica SpA elaboration source).

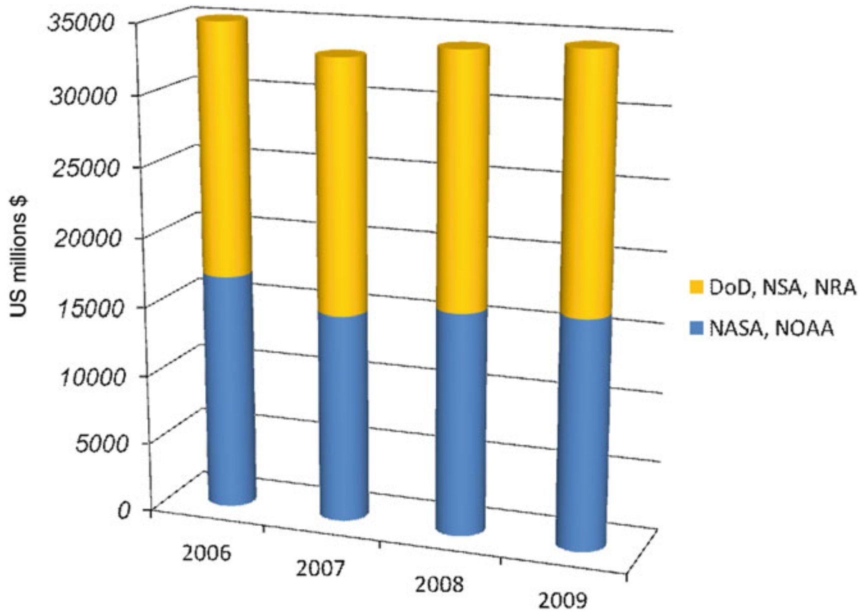


Figure 1.11. Estimated Space Budget USA. (NASA source, ESPI source).

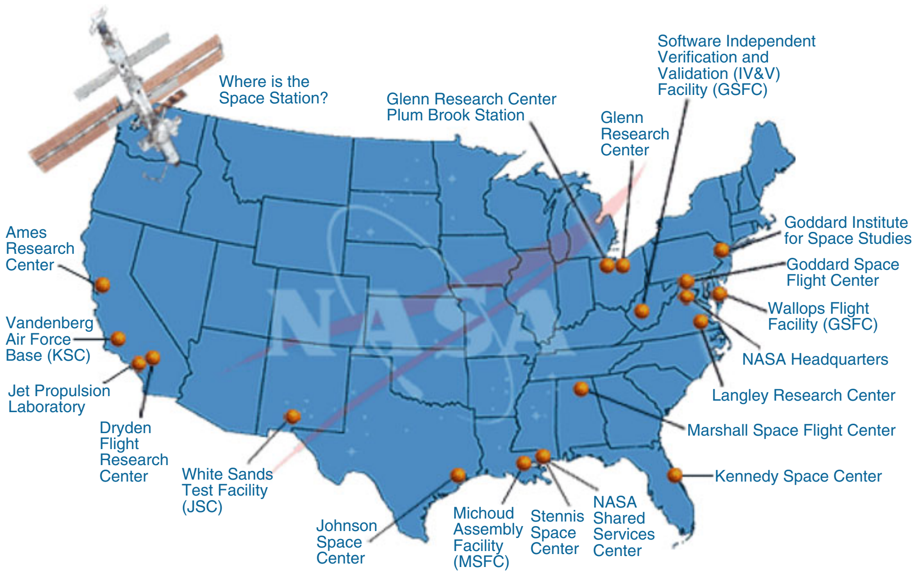


Figure 1.12. Location of the main NASA centers. (NASA source).

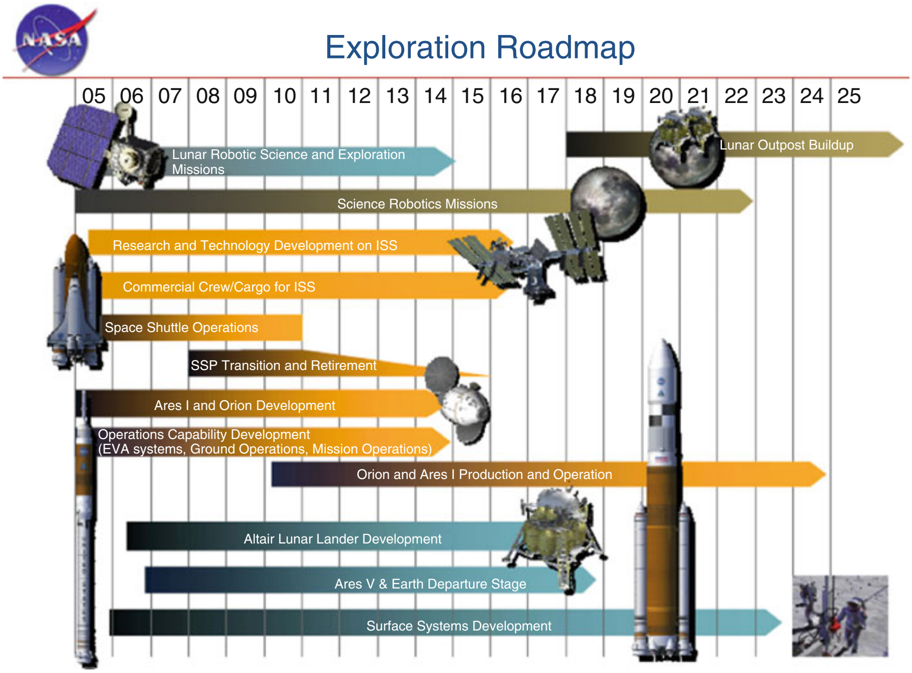


Figure 1.13. NASA planning for the "Constellation" program launched in 2004 and then cancelled in 2010. (NASA source).

At this time the US space policy seems oriented toward a new strategic division of responsibility between the scientific and technological community, with NASA as a point of reference, and the DoD and intelligence agencies as a clearly military point of reference.

One could assume that in the near future US policy will see a broad mandate being given to NASA for world leadership in scientific exploration and research and development and just as broad a mandate to the DoD and Intelligence for security and defense applications.

Access to space and the use of near-Earth space could be co-participated in by private industries operating on a commercial basis cofinanced by NASA.

The situation seems just as uncertain financially as well as strategically. Notice for example in Figure 1.14 the trend in NASA's budget from 2009 to the subsequent years on the basis of presidential requests, on the OMB's forecasts and the pragmatic ones of NASA itself on the basis of a budget which by law cannot be inferior to that of the previous year.

It is not yet officially clear which scenario will be most probable but it appears evident that the difference of several billion dollars will affect NASA's program lines.

The American agency went through a period of change due to the cancelation of the "Constellation" program in which new launchers and spacecraft were to be developed and to the retirement of the three Shuttles of the fleet from 2011.

Figure 1.15 reveals the variation per program of NASA government financing in the period 2010–2012.

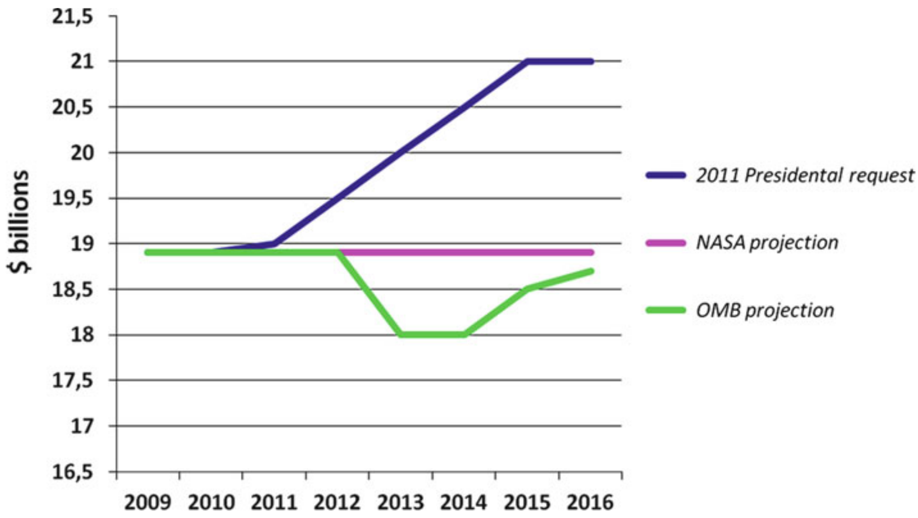


Figure 1.14. Forecasts for NASA's budget from 2009 to 2016. (NASA source).

As we can infer from the 2012 budget, NASA foresees the use of a large part of the 2.4 billion dollars not anymore for Shuttle flight costs, but to increase the expense of commercial flights, that is, to entrust the sending of materials and men to the ISS to private industries, to increase research and development of the technologies and use of the Space Station.

What is not yet clear is the strategy of development of human space exploration for the next decade.

Europe: The European Space Agency ESA

ESA is an intergovernmental agency charged with the development of space capabilities for the continent "for peaceful purposes." ESA began its activities in 1975, but was created 2 years prior during a meeting between the Ministers of ten European countries to integrate two European organizations, ELDO (European Launcher Development Organization) and ESRO (European Space Research Organization) both founded at the beginning of the 1960s.

During its 30 years of existence, ESA has contributed to making Europe a top-ranking space power with a solid industrial base, benefiting from a high level of autonomy in most of the sectors of space technology.

ESA member states number 19 today, but in the future it will be broadened to include 22. The member states are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Norway, the Netherlands, Portugal, the UK, Spain, the Czech Republic, Sweden, Switzerland, and Romania. In addition, Canada and Hungary participate in several projects based on cooperation agreements. As we can see from the list, not all the member states of the European Union are members of ESA and vice versa.

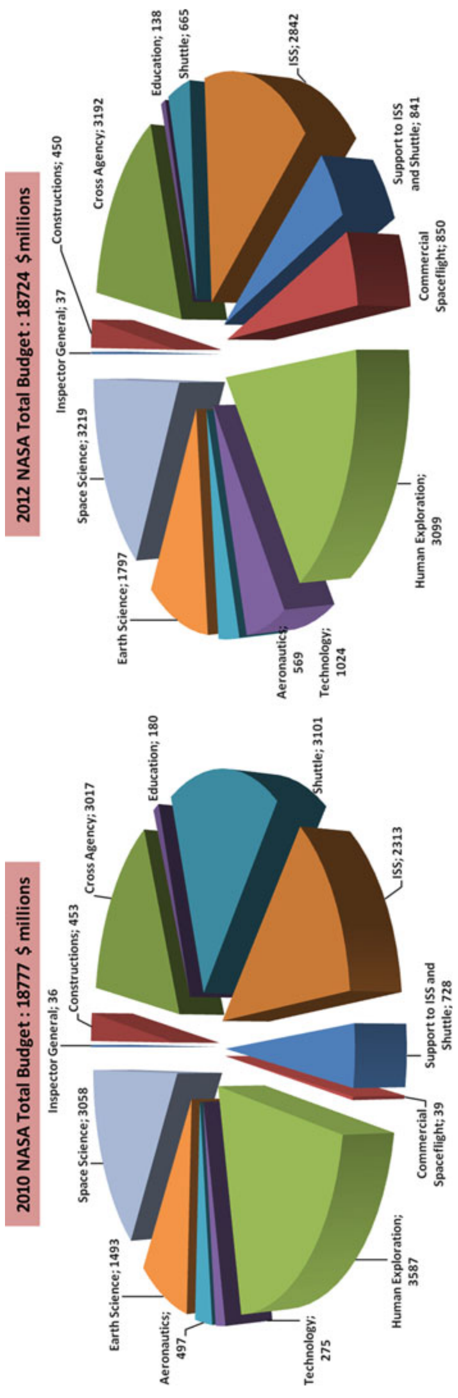


Figure 1.15. Comparison of NASA's 2010 and estimated 2012 budget. (NASA source).

ESA's task is to define and produce space programs. In order to do this, ESA collects, coordinates, and spends financial resources paid by Member States through its national space agencies.

In this way, ESA can undertake programs and activities that are very often superior to those possible through single European nations.

European projects are conceived to study as much as possible the Earth and its surrounding space environment, the Solar System, and the universe in general, but the development of space systems applications, technology, and satellite services is also a major sector.

ESA is a completely independent organization even though it maintains close ties with the European Union based on a framework agreement signed between the European Commission and ESA itself. The two organizations share in fact a joint space strategy and are developing a European space policy according to a common vision.

ESA has its own central headquarters in Paris where programs and policies are decided, but it also has important operational centers in other European countries.

- ESTEC, the "European Space Research and Technology Centre," is the technological center with the greatest number of employees and is located in Noordwijk, the Netherlands.
- ESOC, the "European Space Operations Centre," is the center for the orbital control of satellites and ISS operations and is located in Darmstadt, Germany.
- EAC, the "European Astronauts Centre," is the training center for European astronauts and is located in Cologne, Germany.
- ESAC, the "European Space Astronomy Centre," at Villanueva de la Cañada, near Madrid in Spain, hosts the scientific operations centers for ESA's astronomy and planetary missions, along with their scientific archives. It provides services to astronomical research projects worldwide.
- ESRIN, the "European Space Research Institute," is the center responsible for coordinating the Vega and GMES programs and is located in Frascati, Italy. In addition to gathering, archiving, and distributing satellite data for ESA partners, it functions as a technological information center for the entire agency.
- CSG, the "European Space Port" located in the "Centre Spatial Guyanais" in Kourou, French Guyana, is the European spaceport for the takeoff of ESA's launchers. The center and launch base were created by CNES, the French space agency since the 1970s, and was later notably increased in size under ESA's sponsorship. The CSG is ideally located on the northern coast of South America, which allows space launches over the Atlantic Ocean.
- Ground stations are Salmijärvi, Sweden, Redu, Belgium, Villafranca Del Castillo, Spain and Kourou, French Guiana. The Salmijärvi station near Kiruna, at high altitude, works with satellites that observe the Earth which follow a polar orbit, while the Redu station works especially with telecommunication satellites that orbit over the equator. Operations related to astronomy satellites and scientific programs are carried out at Villafranca. The main role of the Kourou ground station is to communicate with satellites shortly after their launch. ESA also uses a tracking station located in Perth, Australia, and has access to other stations in the world, according to the needs of its missions.

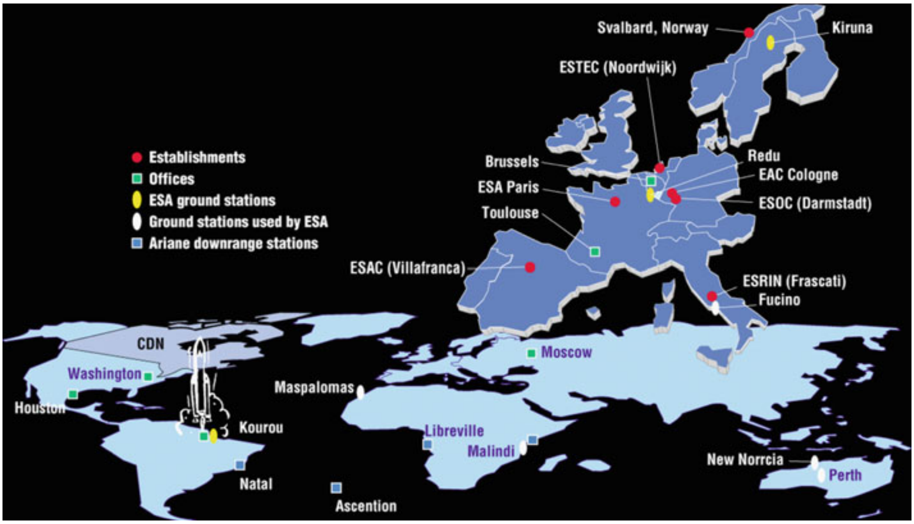


Figure 1.16. ESA locations in the world. (ESA source).

Member States Contribution	: 2778,6 M€
Budget from EU *	: 754,8 M€
Cooperative States	: 5,2 M€
Other budgets (Eumetsat)*	: 206,1 M€
	Totale Budget 2010 : 3744,7 M€

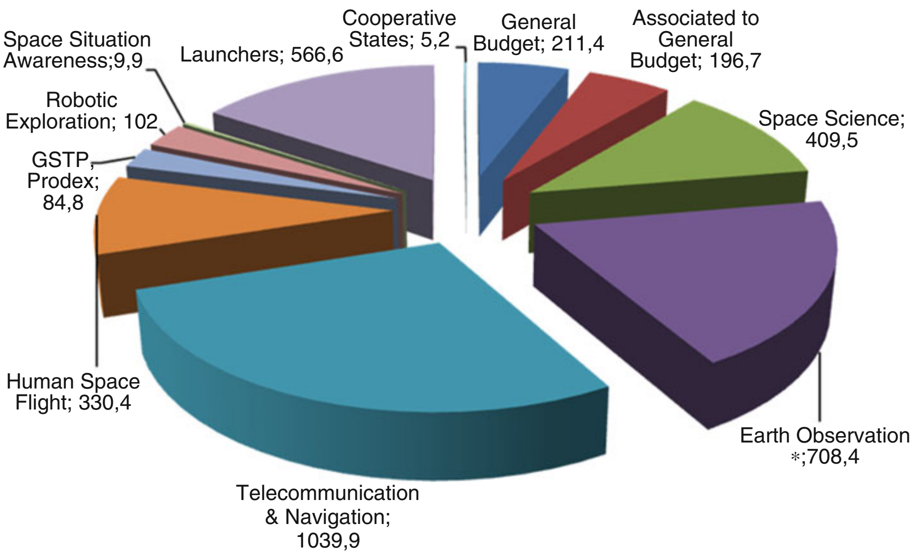


Figure 1.17. ESA's 2010 budget and breakdown of expenditure. (ESA source).

Moreover, ESA has regional offices in Belgium, the USA, and Russia (Figure 1.16).

With over 2,000 staff, ESA's budget in 2010 was about 3,744 million euro, but 754.8 million euro was contributed by the European Union and not by ESA Member States. Breakdown of the expenditures is illustrated in Figure 1.17.

ESA's budget has been stable for many years and if we compare it to the NASA civilian budget, we can see that Europe spends one-sixth of the amount.

In 2011, 18 Member States increased the agency's budget by 7% with respect to 2010, but this increase was mainly generated by France and Germany, as well as by external contributions, such as the European Union with 778 million euro and EumetSat with 233 billion euro. Figure 1.18 illustrates how ESA's budget was divided in 2011.

Space science and general budget operations are called by statute "obligatory" programs by ESA. These programs are funded with an obligatory economic contribution by all Member States calculated on the basis of each country's gross domestic product.

Then ESA develops a certain number of so-called "optional" programs to which each single country is free to subscribe or not, deciding its financial level of participation and support.

The relationship between mandatory and optional expenditures is illustrated in Figure 1.19 according to each member state, relative to the 2008–2009 period. It can be inferred that France, Germany, and Italy were and are to date, in order, the major countries that contribute annually to ESA's budget; in fact, the level of resources invested by these three countries makes up 60% of its total budget.

ESA operates on the basis of geographical sharing criteria. It reinvests in each member state by means of industrial contracts for space programs with an amount almost equivalent to the financing provided by that country.

Approximately 12–18% of the financing of each program is therefore kept by the agency to cover its own operating expenses.

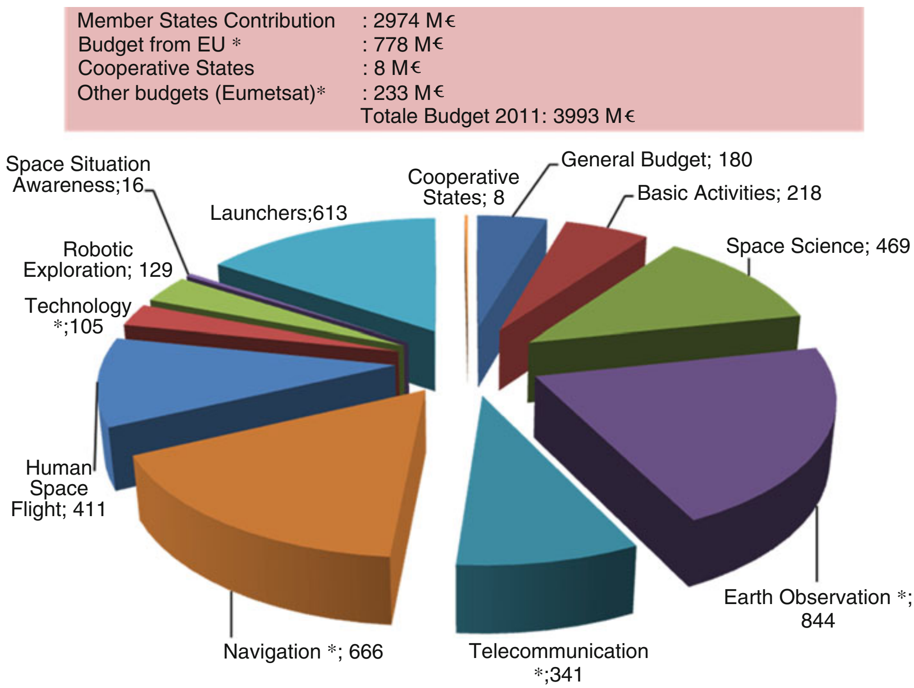


Figure 1.18. ESA's 2011 budget and breakdown of expenditure. (ESA source).

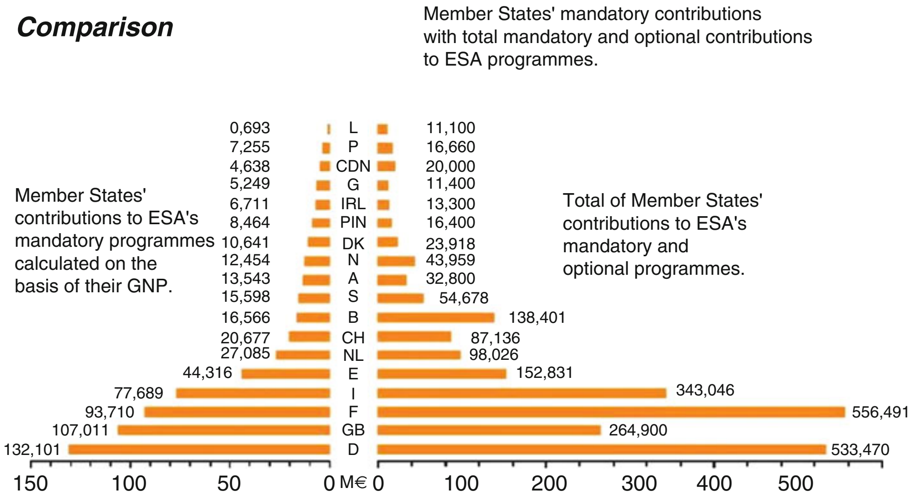


Figure 1.19. Comparison of obligatory and optional expenses for the period 2008–2009. (ESA source).

The rule of geographical distribution, called "Just Return," has been for over 30 years and is to date the fulcrum of European space policy and is a guarantee for the member states that their investments contribute both to the common cause and to the development of their own national industrial sector.

ESA's administration is provided by the Council, the self-governing body of the agency, which periodically meets during the course of each year. The Council defines and approves the guidelines on the basis of which the agency then provides for the development of its programs. Each member state, represented in the Council, from the President of National space agencies, has the right to one vote, according to its size or its existing financial contribution.

The agency is managed by a Director General, elected by the Council every 4 years. Each single research sector has its own Directorate that is under the direct authority of the Director General.

Every 3 years, ESA's Council meets in plenary session with the participation of the European Ministers who have the authority of their respective governments for space operations, and on that occasion, long-term large programs and their financing are discussed and decided upon, thus obtaining guarantees from the highest political level of each country.

The above-mentioned plan is illustrated in Figure 1.20.

ESA's major achievements include:

- Space launchers: the Ariane launch vehicles series since the 1970s has been the strategic instrument for autonomous access to space for Europe. In 2011 and 2012, the Vega launchers, designed by Italy, and the Soyuz were added to the Ariane lineup.
- Satellite platform and payload technologies, developed in the 1970s and 1980s, are the foundation for the current generation of European telecommunication satellites.

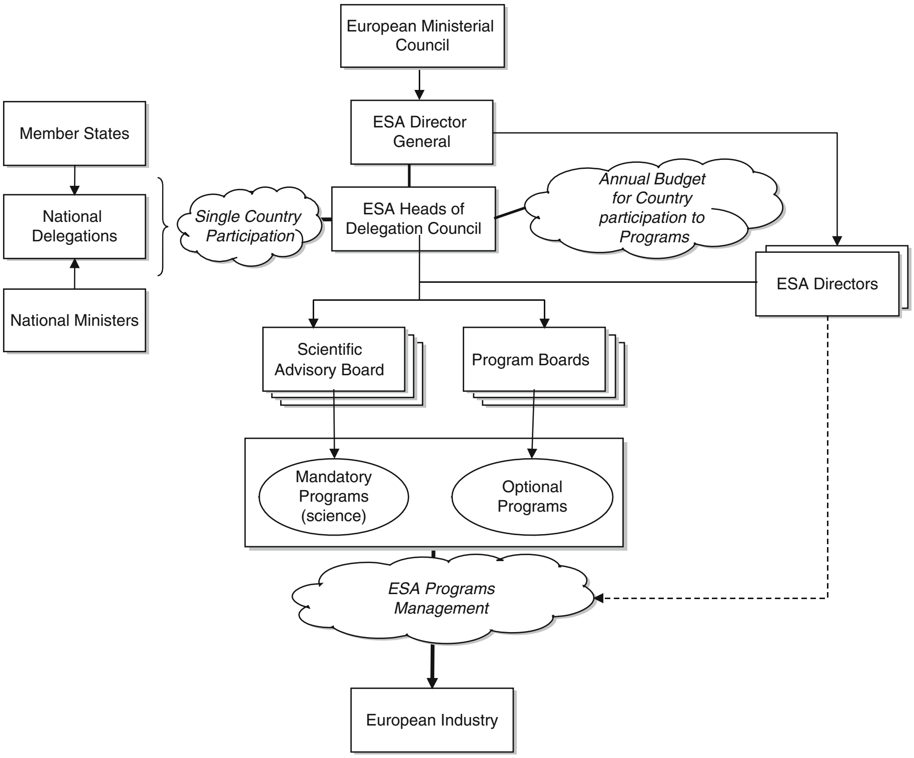


Figure 1.20. Illustration of ESA's operational scheme. (ESA Annual Reports source, Press release source, Finmeccanica SpA elaboration source).

- ESA-built weather and Earth observation satellites are at the forefront in the world for monitoring the ozone hole, ice caps, ocean currents and winds, and other factors that influence the health of our planet.
- Scientific satellites, which have a major role in studying the sun and its effects on the Earth; the study of the solar system planets and comets; the study of the Universe.
- The ESA astronaut corps, which flew in space participating in numerous missions of the Space Shuttle and Soyuz, with various stays on board the Russian space station Mir and the ISS. For the public "call for astronauts" published in 2008, approximately 9,000 men and women all over Europe presented their applications, proof of the space sector's appeal.

Europe: The European Commission

Space operations in Europe in the last 10 years have also witnessed the progressive and significant involvement of the European Commission.

In 2000, the European Union Council approved the recommendation of Parliament for the creation of a "European Space Policy," and consequently in 2003, the European Commission published a "White Book" on space. These formal steps

constituted the first decision-making processes for making the space sector in Europe a strategic factor for the continent.

After a long joint period in 2004, the European Commission and ESA adopted a “Framework Agreement” which regulates the relations between ESA and the European Union and defines the framework of cooperation between the two bodies.

During the fourth “Space Council,” on 22 May 2007, the two organizations approved, at the Ministerial level, a “Resolution on European Space Policy,” the ESP, which established the foundation for a European space policy shared by the European Union, ESA, and the Member States.

Basically, Europe gave itself formal guidelines for a common strategic policy in the space sector and to make strategic infrastructures of these systems, considered by the Union to be components of the security policy for the defense of Europe.

The “European Space Policy,” subscribed to by the authorized European ministers on space, constitutes one more step toward a new European governance in the sector, aimed at a new institutional project that should see the strategic policy of space of the future managed at the highest levels of the European Union and the operational policy of ESA acted upon in coordination with the European Commission.

Through the adoption of the “ESP,” the European Union, ESA, and its member states commit themselves to improving and increasing, wherever possible, the coordination of their operations and their programs and organizing them according to the roles attributed to them respectively, thus avoiding duplications.

The “ESP” is drawn up jointly and a preliminary version of the European space program, that is, a strategic document that supplies an overall vision of its current and future operations foreseen in the next 5–10 years, with a focus on operations foreseen until 2013 in line with the financial outlook of the Union, is released.

Beyond the bureaucratese, the real meaning of the above is in some way revolutionary with respect to the past and present.

In fact, at the present state, within the framework of the European Commission, from November 2004, space policy and its subsequent activities will no longer be managed by the General Research Administration but by the General Direction of Enterprises and industry.

This confirms the strategic importance given to space as an instrument for the development on one hand European security and defense policies and on the other hand the development of environmental, transportation, agriculture and rural development, fishing, research, and other policies.

It seems evident that this process of institutional architecture of a new European governance of the sector cannot ignore the increasingly significant role of the European Commission in the future.

At present, space activities brought forward in the framework of the European Union are the Galileo and GMES programs and several research missions financed through framework research and technological development programs of the European Union.

The framework programs of the Commission are the instruments of multiyear financing which concern various sectors of operation of the Union. For the 2007–2013 period, the seventh framework program has overall 54 billion euro available for investments, but the budget foreseen for the space sector is around 1.4 billion euro, of which 1 billion euro directly contributed by ESA for the realization of Earth

observation space systems ("Sentinels" satellites) and satellite radio-navigation ("Galileo" program).

For "Galileo," the radio-navigation satellite program, the European Commission earmarked in 2008 for the years 2009–2013 an additional 3.4 billion euro that it will put at the disposal of ESA for the completion and launch of the satellite system.

In light of the above, it is evident that the progressive role of the European Commission will not be limited merely to disbursing funds, but also to managing and coordinating, and since the Commission is an organization of the European Union, the fact of coordinating space missions, declared strategic by the Union itself, could become disruptive for space policy.

The operations of ESA primarily concerning science and therefore with peaceful purposes could become "revolutionized" to respond to the increased needs of the Union in the matter of security, environmental monitoring, and cultural diffusion.

However, it is especially the rule of "Just Return" which was a management cornerstone and an instrument of "compensation" of the various needs of each nation, might disappear since the Commission is adopting the criterion of competition and the so-called "best value for money."

Europe: France

France is the European country, which has considered space missions essential for its military, political, and economic strategy since the end of the Second World War.

Since the 1950s therefore, the French space sector has been organized around the defense, research, and civil institutions ministries.

The diagram of Figure 1.21 illustrates the French decision-making political process in space policy.

The French space agency CNES, "Centre Nationale des Etudes Spatiales," was created in 1961 with the mission and objective of coordinating and developing French space policy and of driving European operations.

In fact, France was always a supporter of a strong national space policy even through European space programs and institutions such as ESA, and has structured a governance of the sector where strategic policy is defined at the highest level of state. There is in fact the so-called "Conseil suprême de l'Espace" presided over by the President of the Republic, similar to the USA, which issues the guidelines of French space policy.

The French space agency can manage complex programs thanks to the expertise of its technical centers such as the "Centre Spatial" in Toulouse, where over a thousand people work, the "Centre Spatial des lanceurs" in Evry, which guides and develops the launch operations of Ariane, and the "Centre Spatial Guyanais," CSG in French Guinea where over a thousand member staff are employed and where the launch facilities are located. The centers are illustrated in Figure 1.22.

Figure 1.23 schematically illustrates the level of financial resources used by CNES during the 2006–2009 period for contributions in ESA and for national investment. Through a framework program with its own minister, CNES has affected an effective financial policy that can maintain a stable resource level, of which 685 million for ESA in that period.

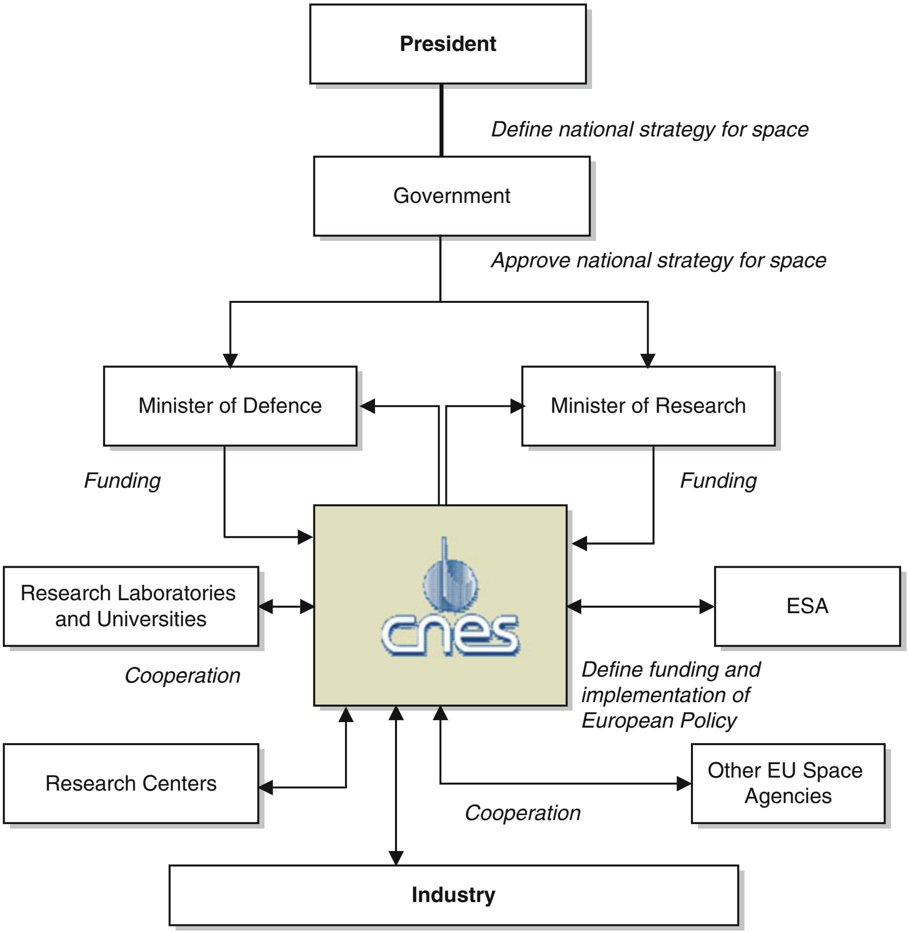


Figure 1.21. French institutional scenario concerning the space sector. (CNES annual reports source, Press release source, Finmeccanica SpA elaboration source).

Figures 1.24 and 1.25 illustrate instead an estimate of the division of French investment in the sector, during the period 2009 and 2010. It is evident that its ESA contribution is almost equivalent to the costs of its national programs.

The highest expenditure item is the Ariane launchers which are a guarantee for autonomous access to space for France, and for Europe; then, scientific missions play an important role, but it is interesting to note that CNES directly manages even military-type operations with the DGA, "Direction Général des Armaments."

CNES is also very active in international cooperation all over the world with application and scientific bilateral programs.

Starting in 2011, CNES foresees increasing its contribution to ESA by 12% with respect to its current value to increase it until 2015. The increase in CNES's budget is the result of a multiyear "contract" signed by the agency with its own minister of reference in order to ensure the continuity of sources for the mid-term period.

Figure 1.22. Location of CNES centers. (CNES source).

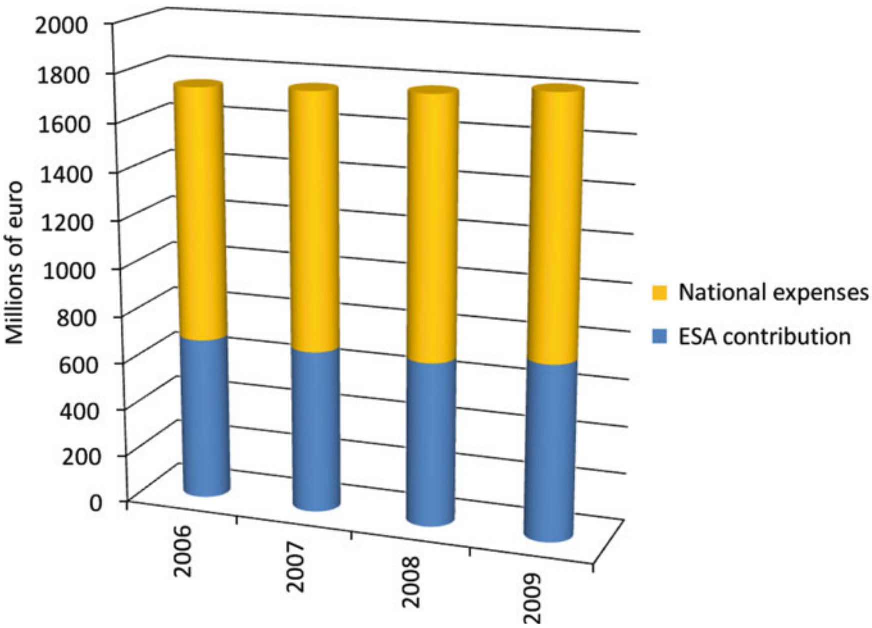


Figure 1.23. Financial resources of CNES for the 2006–2009 period. (CNES source).

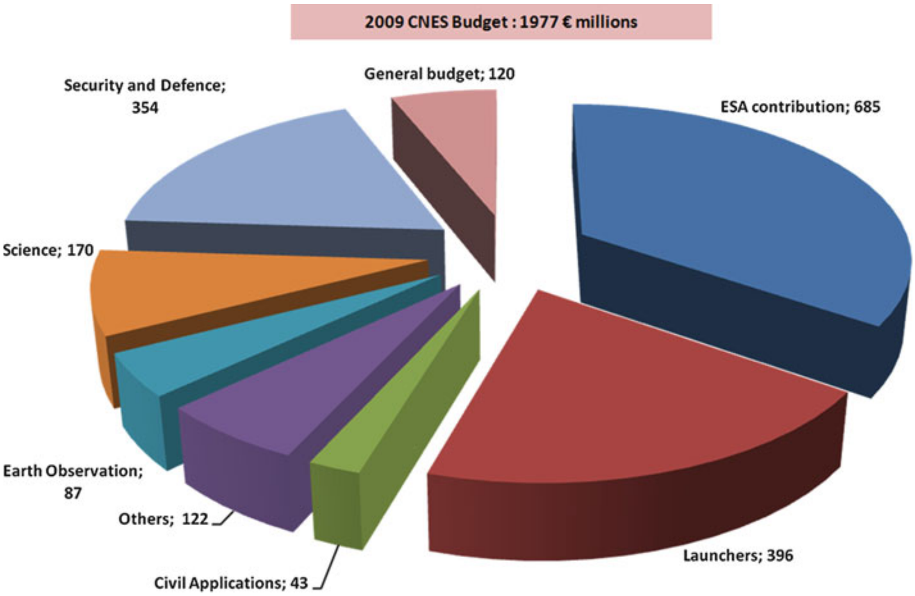


Figure 1.24. Estimate of 2009 CNES' space budget breakdown. (CNES annual reports source, Press release source, Finmeccanica SpA elaboration source).

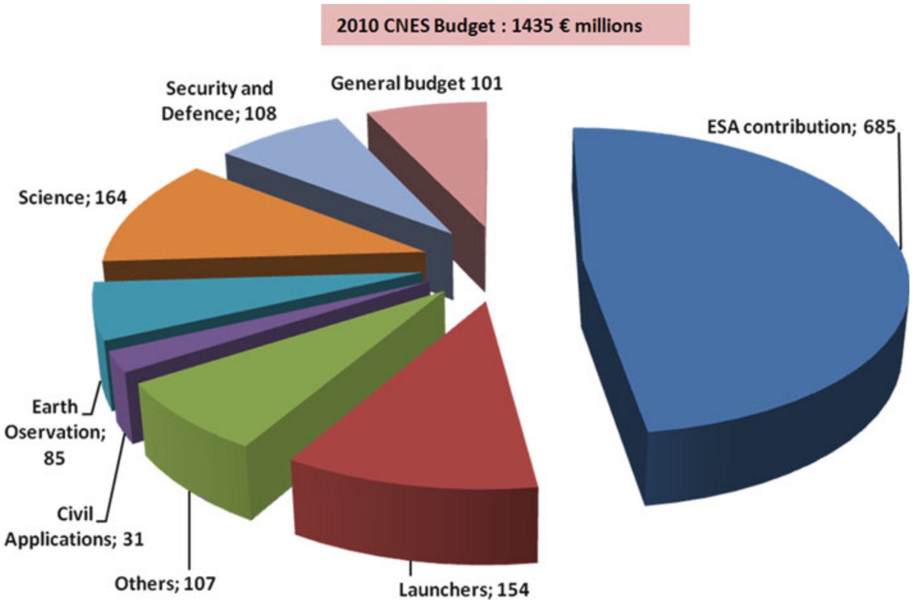


Figure 1.25. Estimate of 2010 CNES' space budget breakdown. (CNES annual reports source, Press release source, Finmeccanica SpA elaboration source).

Europe: Italy

Space activities and national policy are defined by the Italian Space Agency, ASI, established in 1988 as the sole coordinator of efforts and investments that Italy has dedicated in the sector since the 1960s.

ASI is a national public agency that is under the authority of the Research and University Ministry (MIUR) and works in cooperation with various other departments such as the Defense Ministry, the Environmental Ministry, the Industrial Ministry, and others.

ASI draws up the National Space Plan, now called the Strategic Vision Document, DVS, under the supervision, control, and approval of MIUR.

Each year MIUR funds ASI with a special decree of distribution of operational funds on the basis of a request for economic endowment, presented as part of the Financial Law by MIUR to the government.

The institutional process function is schematically illustrated in Figure 1.26.

ASI was reformed with Legislative Decree 128/2003 which established its mission as "*a national public agency with the task of promoting, developing and diffusing, through the agency's missions, scientific and applied technology research in the field of space and aerospace, with the exception of aeronautic research, and the development of innovative services, following objectives of excellence, coordinating and managing national projects and Italian participation in European and international projects, within the framework of coordination of international relations of the Foreign Affairs Ministry, having regard for maintaining the competitiveness for the Italian industrial sector.*"

Within the framework of ESA's International programs, the president of ASI, authorized by MIUR and the Italian government, participates in ESA's councils, and through his delegates, in various program committees, the "Boards," and to specific "Working Groups" for defining and managing ESA's initiatives.

Figure 1.27 illustrates schematically the estimated level of economic resources used by ASI in the 2006–2010 period for contributions to ESA and for expenses at the national level.

Thanks to ASI's operations, the Italian scientific and industrial community has had indisputable success in various space-related fields in the last three decades.

The ItalSat telecommunications satellites, the Cosmo-Skymed Earth observation satellites, the Sax and Agile scientific satellites, the realization of pressurized modules for the ISS, the Tethered satellite, the instruments of the "Cassini" or "Mars Express" probe, and the Vega launcher are only several of the most important achievements made possible with the support of the Italian Space Agency.

Figure 1.28 illustrates the estimated breakdown of expenses of the agency in 2009 and 2010.

We can see that the largest cost items of the agency concern science, Earth observation, and launchers. The data take into account contributions to ESA.

The Strategic Vision Document DVS 2010–2020 was published in 2010. For the first time a 10-year plan for the development of space operations in Italy was defined. Figure 1.29, taken from the DVS, illustrates the 10-year expense forecast, an estimated total of about 7 billion euro divided among the various sectors of operations, while Figures. 1.30 and 1.31 illustrate the division of expenses foreseen for both national programs and ESA program contributions, both existing and future.

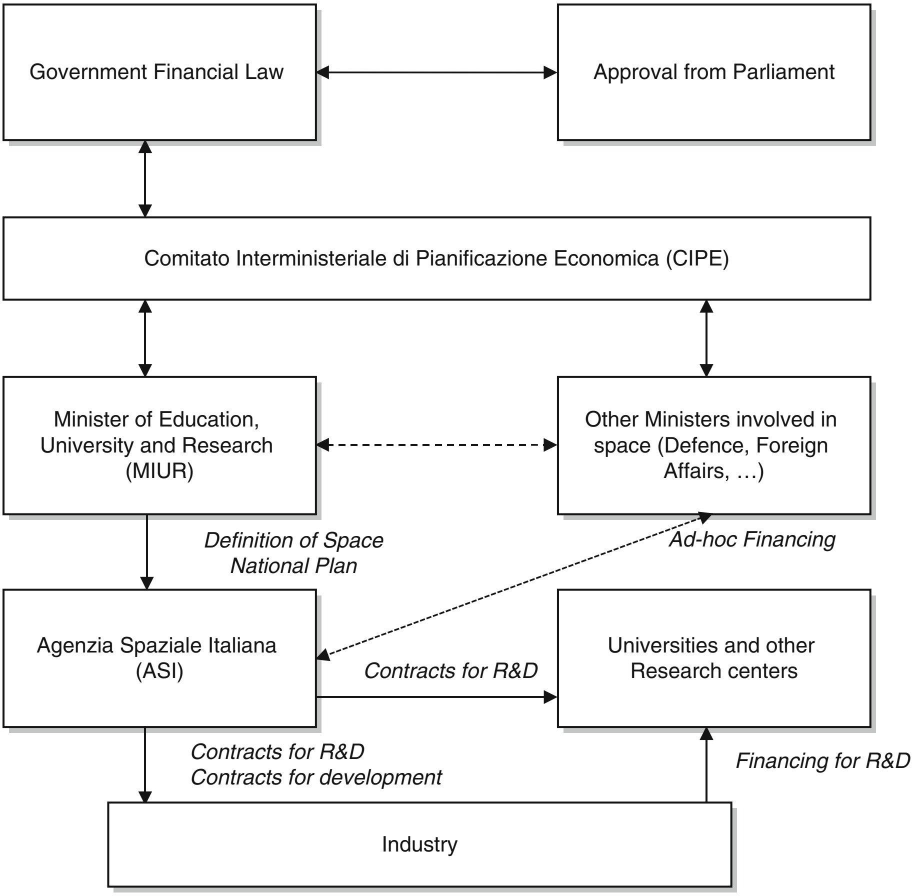


Figure 1.26. Italian institutional scenario relative to the space sector. (ASI annual reports source, Press release source, Finmeccanica SpA elaboration source).

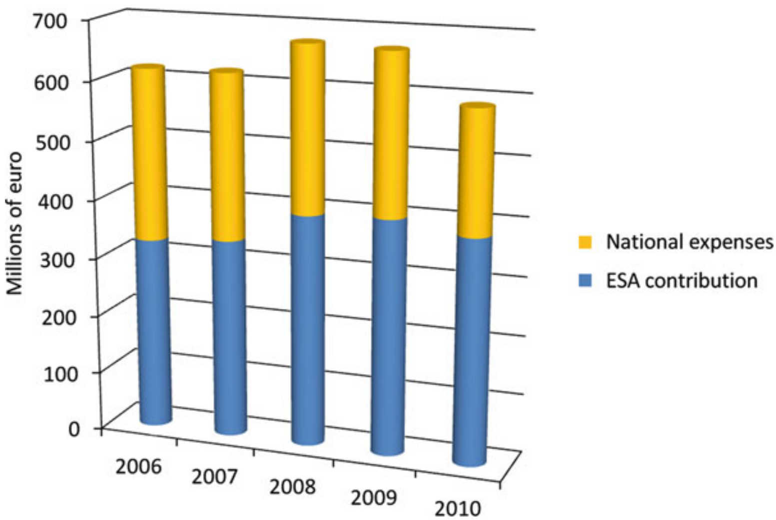


Figure 1.27. ASI's estimated budget for period 2006–2009. (ASI annual reports source, Press release source, Finmeccanica SpA elaboration source).

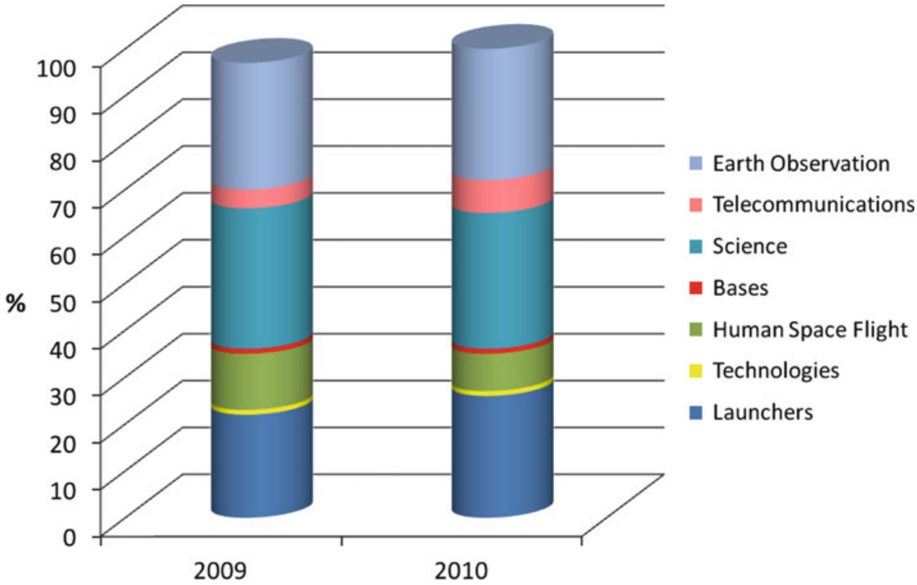


Figure 1.28. Estimate of breakdown of ASI's expenses per sector. (ASI annual reports source, Press release source, Finmeccanica SpA elaboration source).

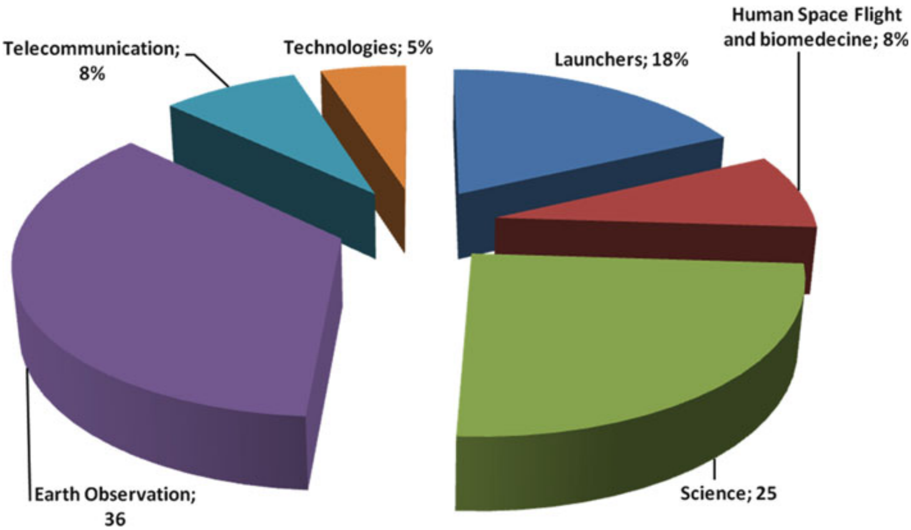


Figure 1.29. Expense forecast for ASI in the 2010–2020 period according to the Strategic Vision Document. (ASI source).

In all the preceding figures, expenses of the European Galileo satellite navigation program are not illustrated. ASI uses special funding from a 2001 law. During the 2009–2010 period, ASI spent about 70 million euro on this specific expenditure, which urgently requires refinancing by a special legislation for the continuation of operations.

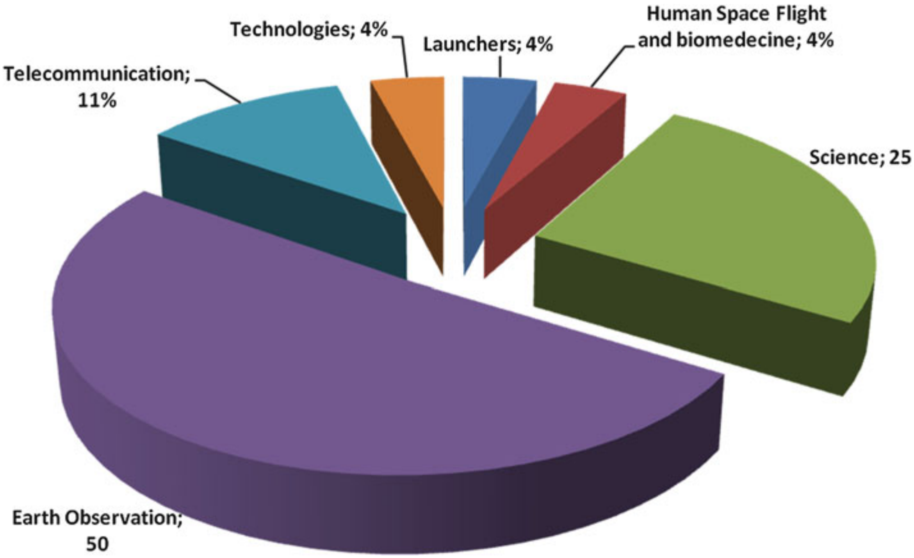


Figure 1.30. Expense forecast per sector of ASI on national programs in the 2010–2020 period according to the Strategic Vision Document. (ASI source).

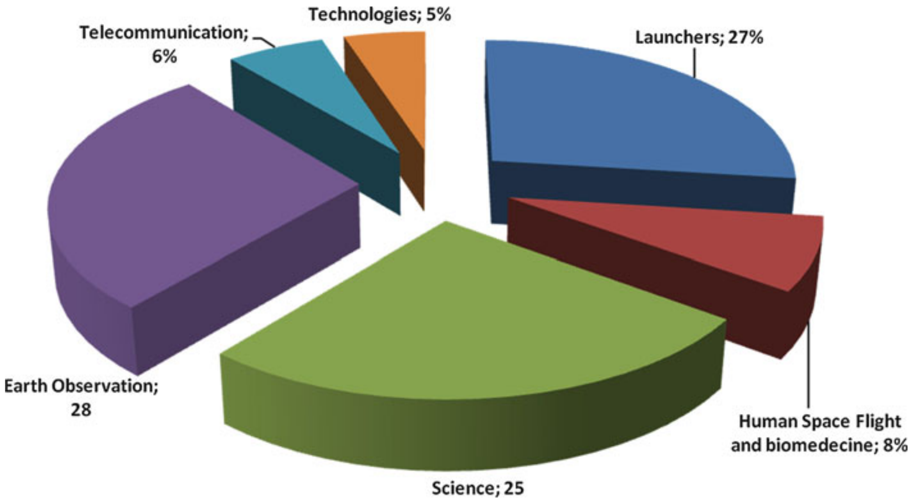


Figure 1.31. Forecast of contributions to ESA from ASI in the 2010–2020 period per sector according to the Strategic Vision Document. (ASI source).

Europe: Germany

Germany is the second contributor country in Europe of ESA, despite the fact that in terms of GDP, it is the first country and the fourth in the world, its contribution to ESA amounted in 2011 at 17.9% of its total budget, compared to France's 18.8%.

In the next few years, the difference between Germany and France will be further reduced since Germany invested 2.66 billion euro compared to France's 2.33 billion euro at the last ESA Ministerial Council at the end of 2008.

The agency of reference is DLR, "German Aerospace Center" which actually includes a group of research institutes within which only the DLR Space Agency is charged with space operations missions for representing the federal German government.

The DLR has 33 research centers dedicated to aeronautics and to space and has about 6,900 employees.

Space operations in federal Germany also received funding from other Länder where aerospace industry is active, but at the level of the central government, the Ministry of Economics determines its political and economic guidelines.

The diagram of Figure 1.32 illustrates the German decision-making political process in space policy, while Figure 1.33 illustrates the 2009 and 2011 estimated DLR budget.

The DLR received funding from the Ministry of Economics and Technology (in 2011 this amounted to 985 million euro) and in 2011, 100 million euro from the Transport Ministry for financing ESA's "Galileo" radio-navigation satellite project.

Germany is also the country that contributes the most to the Eumetsat organization that manages the MeteoSat weather satellites, with 19.5% of the total budget (France contributes 14.9% and Italy 12.2%).

In 2010 DLR published a strategic plan which emphasized ground returns, not only industrial but also application in space affairs. Germany thus manifested its ambition to reinforce the development of the space systems that can ensure economic returns and practical benefits for society.

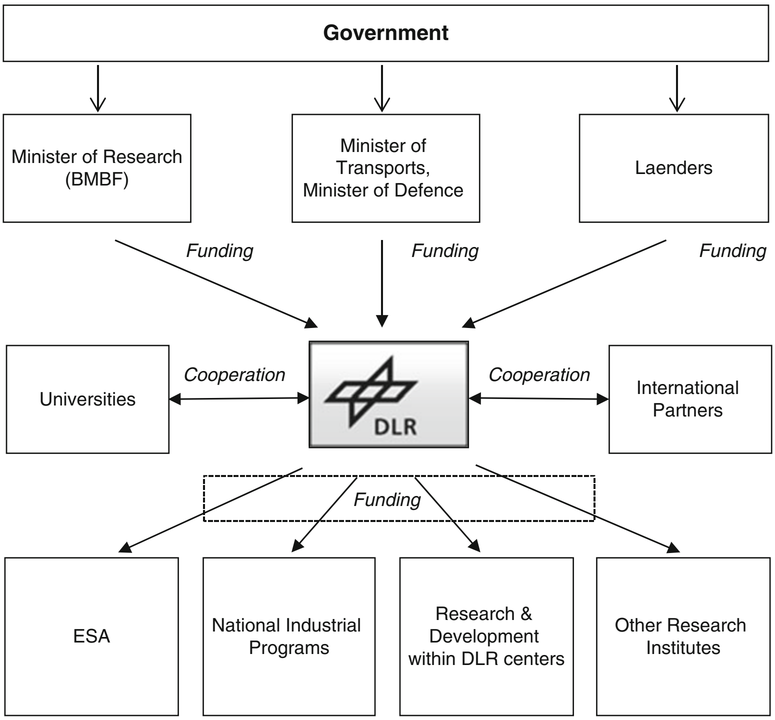


Figure 1.32. German institutional scenario concerning the space sector. (DLR Annual Reports source, Press release source, Finmeccanica SpA elaboration source).

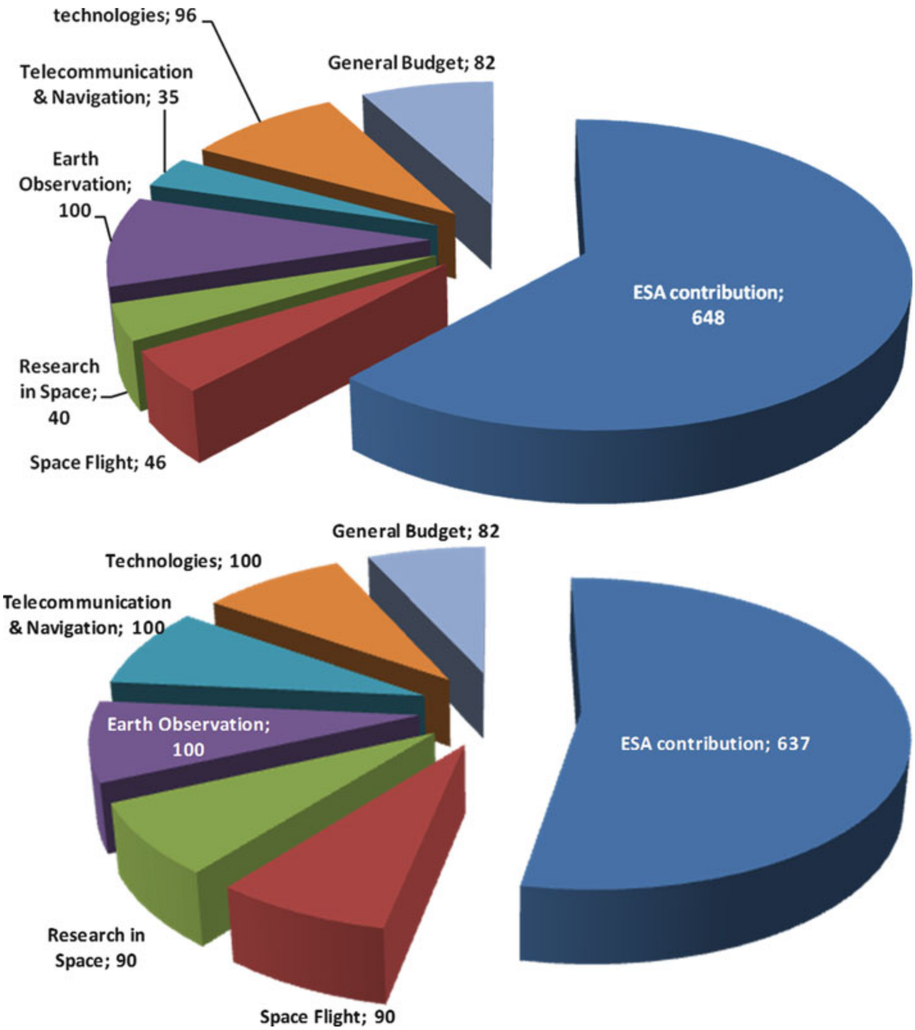


Figure 1.33. 2009 DLR budget and 2011 estimated forecast budget. (DLR source, Air&Cosmos 2257 March 2011 source).

Russia

After World War II in the former Soviet Union, USSR, the space sector was completely autonomous, militarized, and highly strategic, characterized by strong state financing and low international cooperation.

The USSR achieved many results in the space sector. It put the first artificial satellite, the Sputnik, into orbit in 1957, then the first man in space in 1961, and it built the first space station, the Mir, in 1986.

Space policy was directed by the government's chief executive and the management of space affairs was under the authority of military organizations.

The fall of the Soviet system in 1990 brought about a decline in space missions that were harmed by the lack of a legislative framework of reference, with the subsequent drastic reduction of space sector staff (a reduction of 200,000 employees in less than 10 years) and the type of programs.

In 2000, however, the Russian government once again considered the space sector as one of its main institutional priorities and drew up its first federal space program in 2001–2005.

The Russian space agency Roscosmos RKA was created to put this program into place.

At the same time, the level of industrial international and government cooperation was increased with the USA, Europe, and India.

Today the most influential bodies in defining Russian space policy are RKA Roscosmos and the Defense Ministry.

The main objectives of the RKA are:

- To define the federal space program with the Defense Ministry, the Russian Science Academy, and other Ministries
- To define and implement national policy concerning space research and the use of space for peaceful purposes
- To regulate and coordinate space affairs with those of the space industrial sector
- To establish international cooperation
- To define and fund space research and development programs
- To develop space solutions for the economic and social well-being of Russia, to develop and guide Russian space sector organizations
- To define the budget aimed at the space sector with the Defense Ministry

The main objectives of the Defense Ministry are:

- To participate in the definition of the national space program to define the requirements of military space technologies and dual systems to define military procurement
- To define the budget for the military space sector to provide ground support infrastructures
- To manage launch infrastructures and the operations of spacecraft to define the national space launchers plan
- To take part in implementing space programs for civilian use

The diagram of Figure 1.34 tentatively illustrates the Russian decision-making political process in space.

In the federal space program 2006–2015, 8.9 billion euro are shown for civilian space operations. Additional 5.3 billion euro are from nonspecified private investments. Military expenses are not detailed.

Additional official information was given by Russian Prime Minister Vladimir Putin on 12 January 2011 during a press conference where he stated 115 billion rubles (in the current exchange 2.93 billion euro) for the 2011 federal space budget. He confirmed that Russian priorities were to complete the "Glonass" satellite system that is analogous to the American GPS and to improve launch systems and relative launch bases.

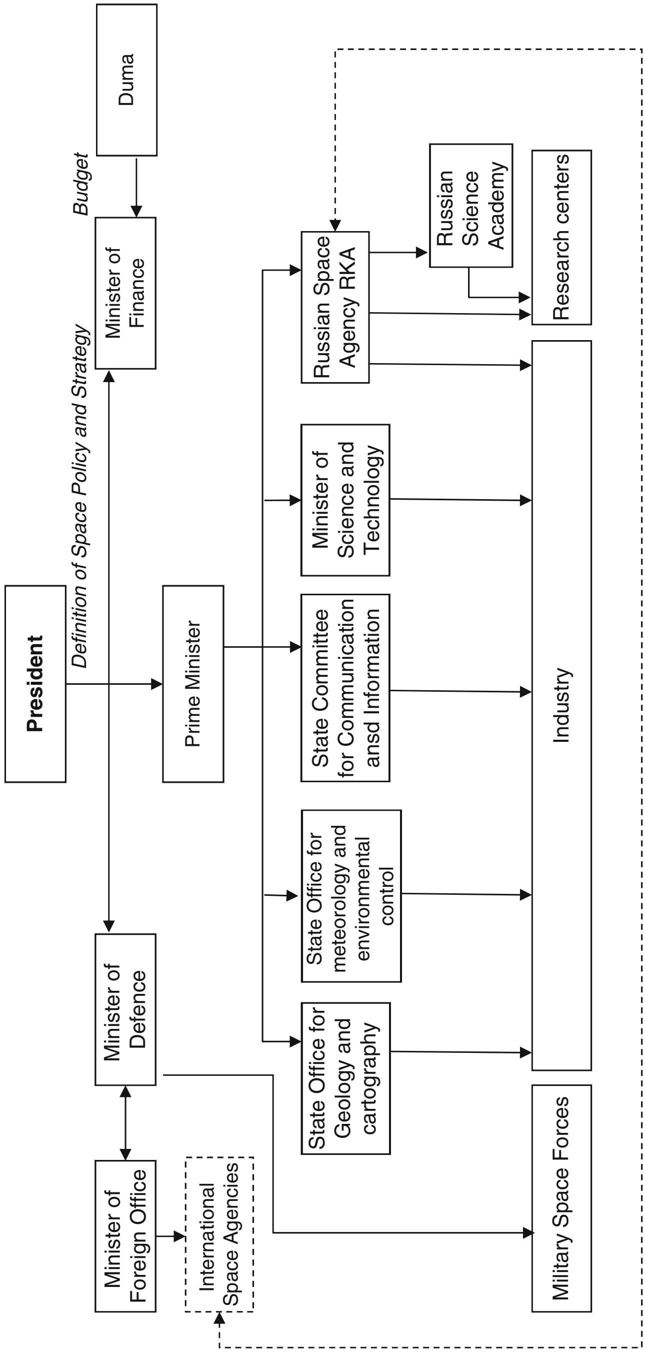


Figure 1.34. Russian institutional scenario concerning the space sector. (Jane's online source, RKA web site source, Press release source, Finmeccanica SpA elaboration source).

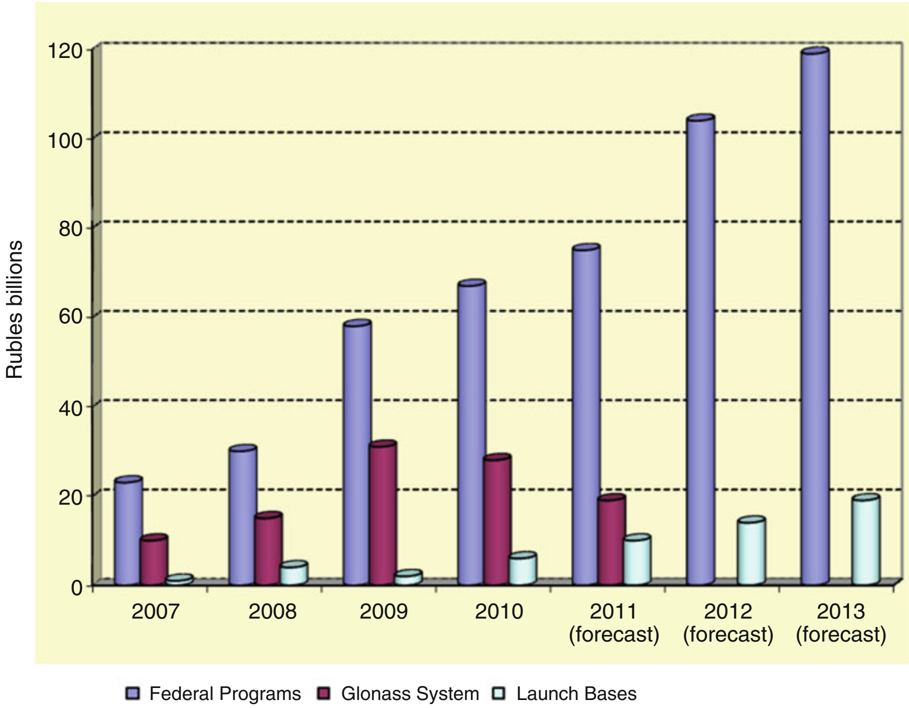


Figure 1.35. Estimated annual investments of the Russian space program in the 2007–2013 period. (Air&Cosmos 2263 April 2011 source).

Accordingly, in April 2011 at the same time as the celebration of the 50th anniversary of Yuri Gagarin's first of 12 April 1961, the RKA spelled out economic and program elements.

Russia's space budget, which in 1999 had fallen to its lowest level, equal to about 145 million dollars, was constantly growing at that time. Figure 1.35 illustrates an estimation of the progress of annual investments of the Russian space program from 2007 to 2013.

In 2010, the Russian space budget was therefore increased by 10.9% compared to the previous year and represents about 88% of the government's general budget.

The strategic Glonass program has a dedicated fund. It is expected to be concluded in the next few years with the complete launch of its satellite constellation.

Budget forecasts until 2013 increased to 28% on an annual basis, a confirmation of the government's continuous attention to this sector.

The main Russian industries that benefit from government financing are Khrounichev, NPO EnergoMach, and NPO Machinostroenie, which develop launchers and satellites.

Military space programs in a lateral sense are included in this budget, but could benefit from additional unknown financing.

India

The importance of the space sector in India is highlighted by the organizational structure that depends directly from the prime minister as illustrated in Figure 1.36.

The main space government institutions are the "Space Department" and the "Space Commission," but the political and operational approach are centralized because the technical competences of the sector are centralized since technical competences are concentrated on the ISRO Space Agency, whose executive is also the head of the "Space Department" and the "Space Commission."

The "Space Department," created in 1972, is responsible for the definition of the country's space programs. It coordinates and defines the guidelines for the other centers and national space laboratories and supports ISRO for remote sensing and is responsible for receiving, processing, and distributing satellite data. In addition, it supports the "Physical Research" laboratory which is the main research center for the country.

The "Space Commission" defines the highest level policies of the sector.

Finally, the ISRO agency is responsible for all space programs and manages international partnerships. It is responsible for the development of satellite launchers, managing the development contracts with industries.

India has developed complete long-term technical and industrial competences all along the value chain, from manufacturing to operations including supply of satellite services, and is therefore a formidable autonomous player with over 16,000 employees in the sector.

At the moment, it has not yet developed astronaut capability.

Figure 1.37 schematically illustrates estimates of the economic resources used by ISRO for the 2006–2011 period and shows a significant increase in spending for this sector.

This increase should be confirmed in 2011–2012, to over 1.4 billion dollars, and among main programs where there should be a significant increase in spending we note habitable flights at about 25 million dollars, heavy launcher GSLV-III at about

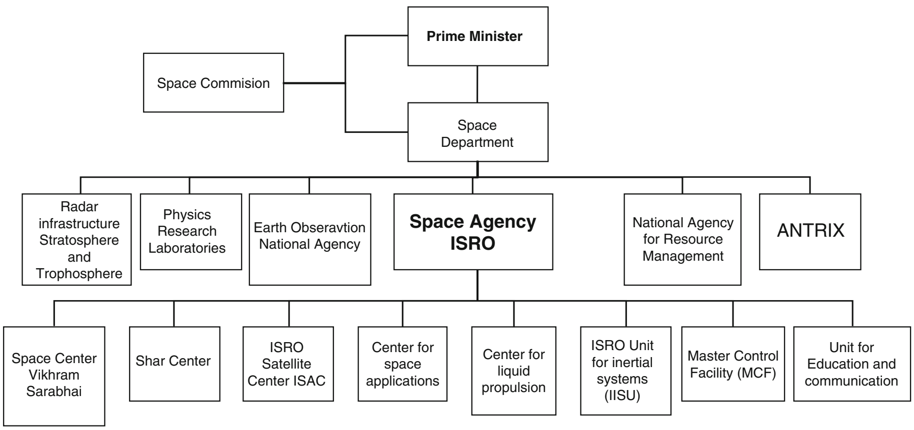


Figure 1.36. Indian institutional scenario regarding the space sector. (Jane's online source, Press release source, Finmeccanica SpA elaboration source).

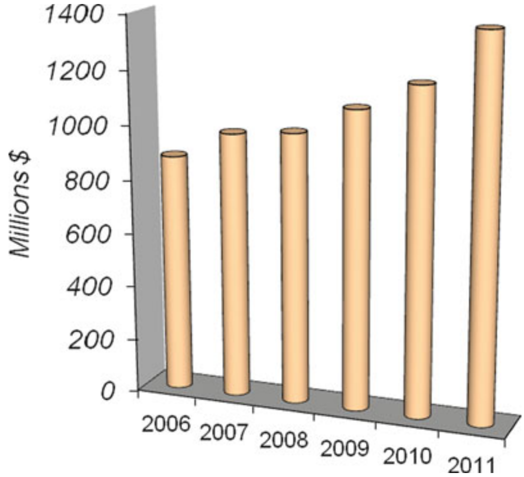


Figure 1.37. ISRO estimated budget for 2006–2011. (Finmeccanica SpA elaboration source, ESPI source, Air & Cosmos 2255 4 March 2011 source).

100 million dollars, the lunar probe Chandrayaan-2 at 20 million dollars, and the advanced telecommunication satellite at 110 million dollars.

China

Initially, in the 1950s and 1960s, Chinese space activities were directed by the ministry of the aeronautics industry, MOA.

In 1988, the MOA was expanded and renamed Ministry of Aerospace Industry-MOS.

A true space agency was created on 4 April 1993 when MOS was split up to the China National Space Agency-CNSA and in the China Aerospace Corporation-CASC.

The CNSA then became the civilian agency of the People's Republic of China for the nation's space development and was responsible for guiding policies, while the CASC developed programs.

This subdivision was considered unsatisfactory by both agencies since they actually remained one single large agency that shared many employees.

In 1998, therefore, the government restructured and divided the CASC into many autonomous agencies that were subordinate to it, called "Academies."

The government's intention was to create a competitive system similar to the West's where different companies compete to receive contracts from government agencies, first of all the CNSA.

The complex political system has in some way influence on the Chinese space sector, which is schematically illustrated in Figure 1.38.

The CNSA performs the following functions:

- Draws up development plans for the aerospace sector
- Is responsible for planning and defining the sector's objectives

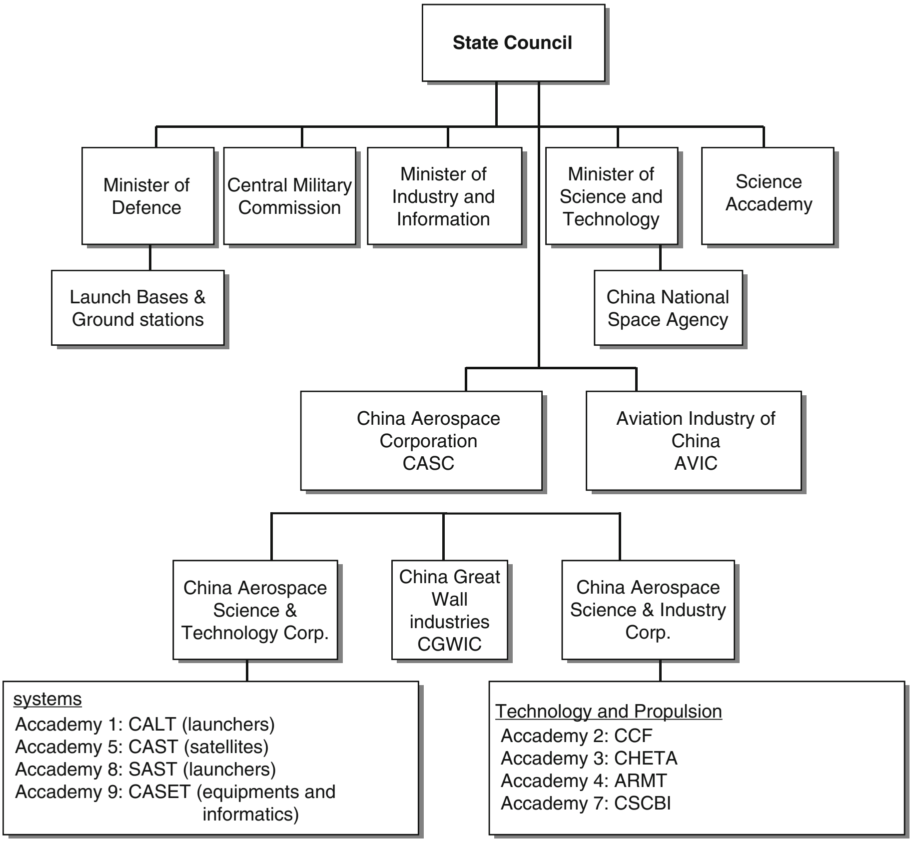


Figure 1.38. Chinese institutional scenario relative to the space sector. (Janes' online source, Press release source, Air & Cosmos 2132 June 2008 source).

- Is responsible for organizing, verifying, and approving nationally relevant research programs, in addition to supervising them and coordinating research
- Is responsible for exchanges and international cooperation in the space sector

The CASC has primary control over space programs, being in fact the only industrial contractor of the Chinese space program.

It is a government agency which as we have stated is divided into subordinate agencies which can plan, realize, launch, and operate satellites, launchers, strategic and tactical missiles, and on-ground equipment and facilities.

The China Great Wall Industry Corporation CGWIC is the business branch of CASC and concerns itself with the import–export of launchers and Chinese satellites.

The corporation has over 110,000 employees and its registered capital is 1.1 billion dollars.

Chinese space programs are not transparent regarding financing and official documents of the CNSA and CASC do not report any budget data.

Unofficial estimates of an annual budget vary between 1.5 and 2.5 billion dollars, but there is no official confirmation of these figures.

The current Chinese situation for the space field is similar to the Soviet Union of the 1960s and 1970s when the country's market did not yet have Western values. The yen has an artificial development and the cost of work is significantly inferior to Western standards. For example, we can see that in 2007 the GDP/inhabitant declared in China was 2,000 USD, while in Japan, in the same geographical area, was 33,000 USD, 16 times higher.

Broadly speaking, if we wish to multiply the Chinese space budget, estimated at 2.5 billion dollars by 16, we would get a value relatively comparable to the American civilian and military budget.

Confirming this, there is an interesting data we can extrapolate from what was officially declared by one of the two vice-administrators of the CNSA upon his visit to the USA in April 2006 (ESPI source) according to which China spends for its work force of about 200,000 in the sector a little less than 400 million euro per year.

These data compared to comparable values in the USA or in Europe are absolutely out of scale compared to the Western market economy.

China is the only country in the world, after the USA and Russia, to have acquired autonomous capability in sending astronauts into space, and this is a result of the evident Chinese political doctrine of following strategic objectives of military supremacy on the global scale.

Japan

In the 1960s, space research was begun in Japan. Two separate agencies were set up, one for applications and one for science, which developed programs, satellites, and launchers, with relative launcher bases, in a separate and autonomous way.

One agency was NASDA-National Space Development Agency, founded in 1969 located at the Tanegashima Space Center, on Tanegashima Island, about 115 km south of Kyushu. The other agency was ISAS which was under the authority of the Ministry of Education; it was part of the University of Tokyo until 1981 and was located at the Kagoshima Space Center.

The government expanded space activities in 2003 and merged NASDA, the National Aerospace Laboratory of Japan (NAL) and ISAS into one single agency, the Japan Aerospace exploration Agency-JAXA.

The JAXA Agency therefore became a single government agency for space affairs in Japan that interacts with other public agencies that are connected in one way or another to space research.

Figure 1.39 illustrates the institutional schema of space sector "Governance" in Japan.

JAXA has inherited many research centers and offices in Japan from NASDA, ISAS, and NAL, including:

- Central headquarter in Tokyo
- Earth Observation Research Center (EORC), in Tokyo
- Earth Observation Center (EOC) in Hatayama
- Noshiro Testing Center (NTC)—established in 1962, and involved in the development and testing of motors used in rockets
- Sanriku Balloon Center (SBC)—used for balloon experiments since 1971

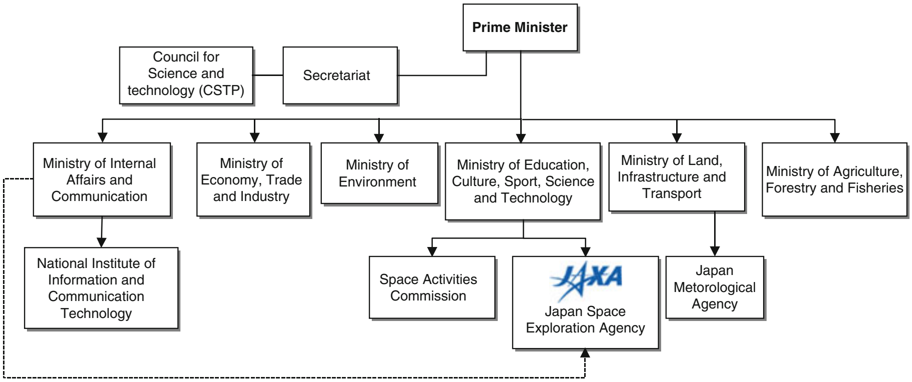


Figure 1.39. Japanese institutional scenario for the space sector. (JAXA source, Press release source, Finmeccanica SpA elaboration source).

- Kakuda Space Propulsion Center (KSPC)—develops motors for rockets, and works mainly with motors and liquid fuel
- Sagamihara Campus—develops and verifies equipment for rockets and satellites. There is also an administrative office.
- Tsukuba Space Center (TKSC)—it is the Japanese space network center and is involved in development and research on satellites and rockets, concerned with tracking and control of satellites. Equipments for the Japanese Experiment Module, Kibo, of the ISS are developed here and astronaut training.

Figure 1.40 shows the geographical location of various centers located all over the island.

Figure 1.41 schematically illustrates the estimated level of financial resources used by JAXA in the 2006–2008 period and shows a substantially stable budget.

However, this budget could increase in the near future because of a radical political change that occurred in 2008. In fact, in February, Japan appointed a minister for "Space Development" for the first time after the war for security and defense. In so doing, it broke a condition it had kept for decades, preventing the pacifist nation from starting up space programs for defense.

The appointment was put into effect after the approval of a new law, which allowed the use of space for defense purposes, a prohibited activity for Japan after World War II but which was considered necessary because of growing fears of military threats in the Asian area.

The new law's objective was to remove any legal obstacle to the building of new-generation spy satellites, and to the innovation of the national space industry.

In fact, Japan has increased military research ever since North Korea launched a ballistic missile in 1998 near to Japanese territory. Space missions are of major interest under this perspective.

Japan has also expanded its space exploration program and is presently conducting one of the largest robotic lunar missions in the world of the last decades.

It is also conducting innovative robotic explorations of distant objects, such as asteroids, attempting to land probes on these objects to bring back material back to Earth.

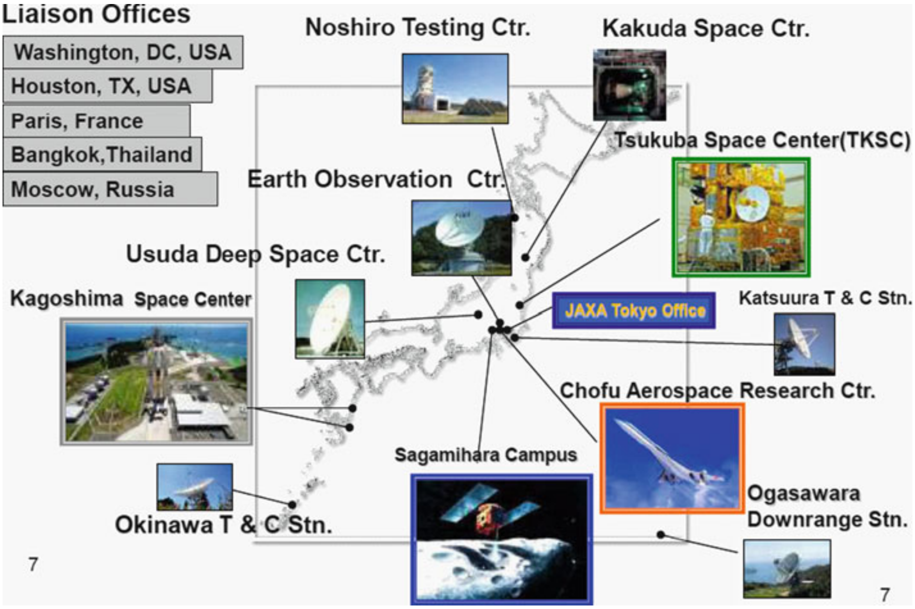


Figure 1.40. Location of various JAXA centers in Japan. (JAXA source).

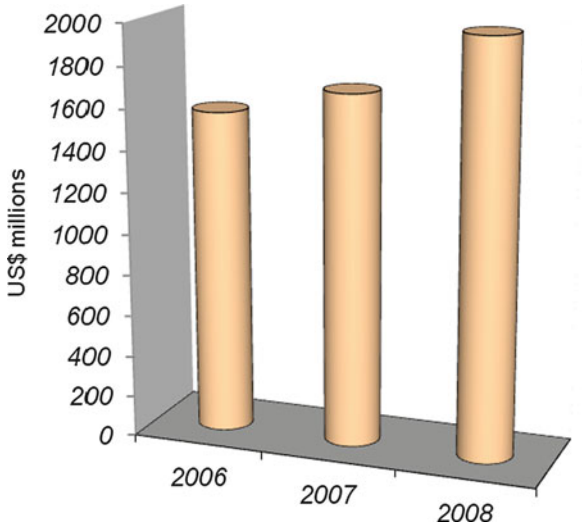


Figure 1.41. Estimate of JAXA investments for 2006–2008. (Press release source, Finmeccanica SpA elaboration source, ESPI source).

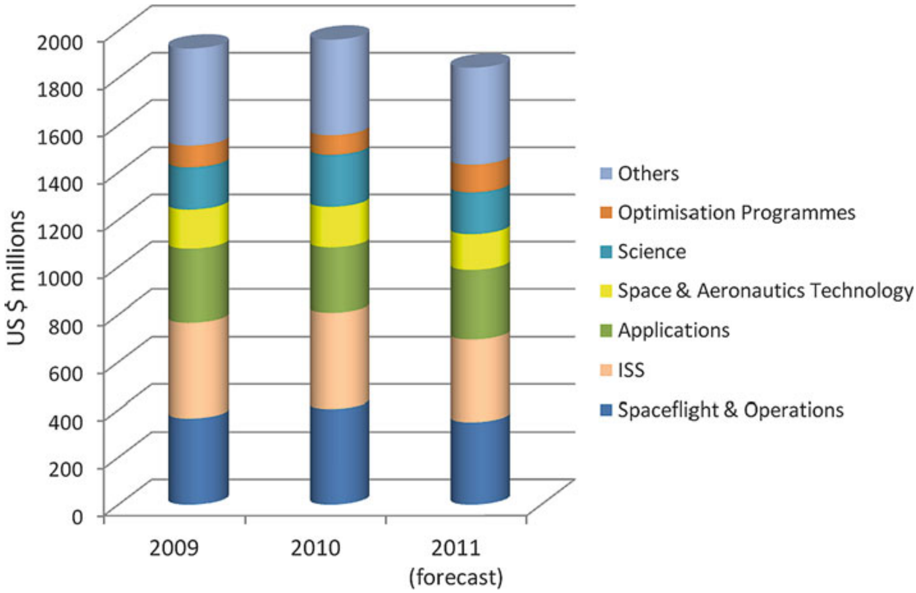


Figure 1.42. Estimate of 2009–2011 budget with sector breakdown. (JAXA source, Press release source, Finmeccanica SpA elaboration source, ESPI source).

All these activities provide proof of extremely advanced engineering and scientific capabilities that however must face the economic crisis, which is also affecting Asia. Figure 1.42 shows the estimated budget forecast for JAXA in 2011 which is 4% less than the 2010 budget. It also illustrates the sector breakdown of investments.

1.5. Definition and Segmentation of the "Space Market" in the World

If we turned back our minds through the years today to the "cold war" period, that is the 1950s, 1960s, and 1970s, it would be difficult to imagine that space affairs in the world could have become an industrial and services sector that could move 100 billion dollars a year in the third millennium.

In our days, the space market cannot be solely identified with industrial production, which is, manufacturing, of space systems, but also of the sale of services and applications that derive from them.

Space services worldwide at this point surpass manufacturing as business share.

Figure 1.43 shows the division in 2009 of business volume, worldwide of about 130 billion dollars, relative to space missions in the world, both manufacturing and services.

The services share of business is much larger than manufacturing; the value of space services sales, driven by pay-tv television packets, was valued at 68 billion dollars in 2009.

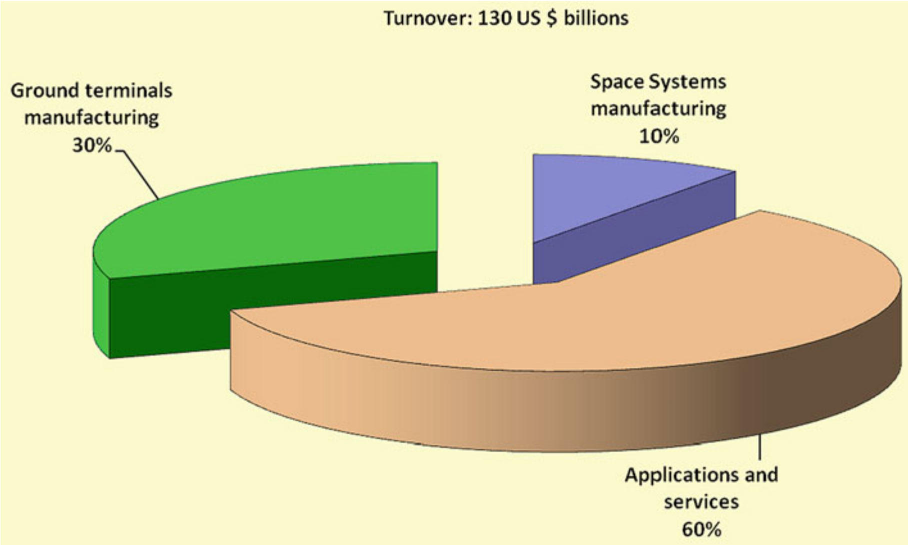


Figure 1.43. Division of worldwide business volume in the space sector for 2009. (Press release source, Finmeccanica SpA elaboration source, ESA source).

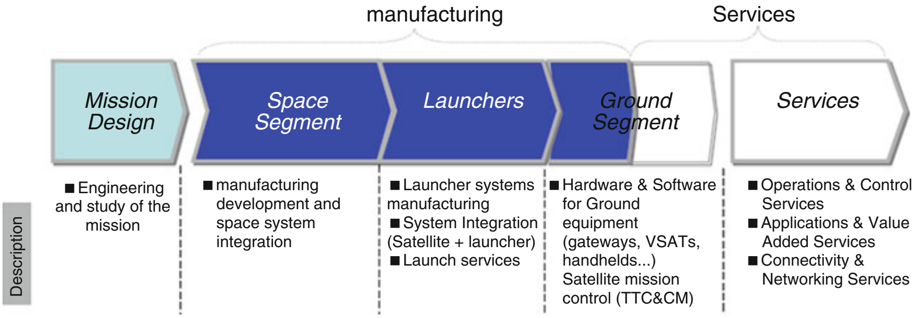


Figure 1.44. Value chain for the space sector.

Ten percent of spending for manufacturing of space systems amounted to about 32 billion dollars of which however 47% was only dedicated to military systems, for which the USA alone invested 29 billion dollars (only unclassified programs, and not classified ones and therefore not traceable).

Thirty percent of ground terminal costs are largely due to global diffusion of GPS receivers for radio localization and navigation.

Therefore, 130 billion dollars represent the global "market" for the space sector in 2009 and in 2010, the amount should be about the same value.

In order to understand the segmentation between manufacturing and services better, we examine the value chain for the space sector in Figure 1.44 that defines space market range.

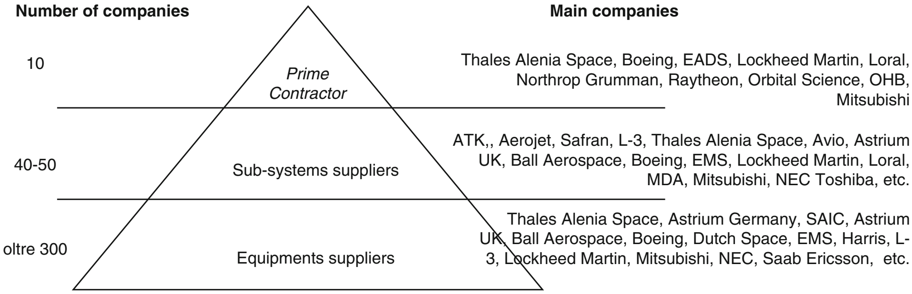


Figure 1.45. The industrial pyramid in the space manufacturing sector.

The world satellite manufacturing market includes six large "*Prime Contractors*" with the ability to supply complete space systems and several dozen suppliers of subsystems.

Several of them are also "*Prime Contractors*" in special cases (e.g., in national or scientific satellite programs). The suppliers of devices and equipment, the so-called "payloads," are numbered to be over 300. Prime Contractors and subsystem specialists are part of this group, either directly or through controlled companies.

Figure 1.45 outlines the above industrial state of affairs.

On the other hand, the so-called "services and applications market" is not as easy to outline as manufacturing because there are many operators worldwide who operate or use space systems for telecommunications, imaging, and radio-navigation services.

The Manufacturing Market

Because of its strategic nature, the space sector essentially depends on institutional budgets (space agencies and research institutions), whereas the institutional market prevails in manufacturing with respect to the commercial one. Moreover, almost 80% of the world institutional market is American and is accessible only to American companies given its strategic and military value.

Recently, the European Union recognized the space sector as strategic, explicitly mentioning it in the text of the new "Treaty of the Union." However, today main civil programs are basically developed only within ESA, while military programs are fragmented among national initiatives.

Therefore, the commercial market has been a driving force for European industries, especially for the realization and sales of telecommunication commercial satellites and Ariane launchers. In the most recent years, this market has grown less compared to the boom years of the 1990s. However, it is slowly recovering. The commercial drive stems from the increase in broadband communication services and especially from the widespread diffusion of pay satellite televisions.

Industry has been concentrated very much in manufacturing with a very limited number of global competitors—the "*Prime Contractors*"—both in Europe and in the USA.

The entrance of emerging countries into the market should be noted, especially China and India, which have put into place extremely ambitious space plans.

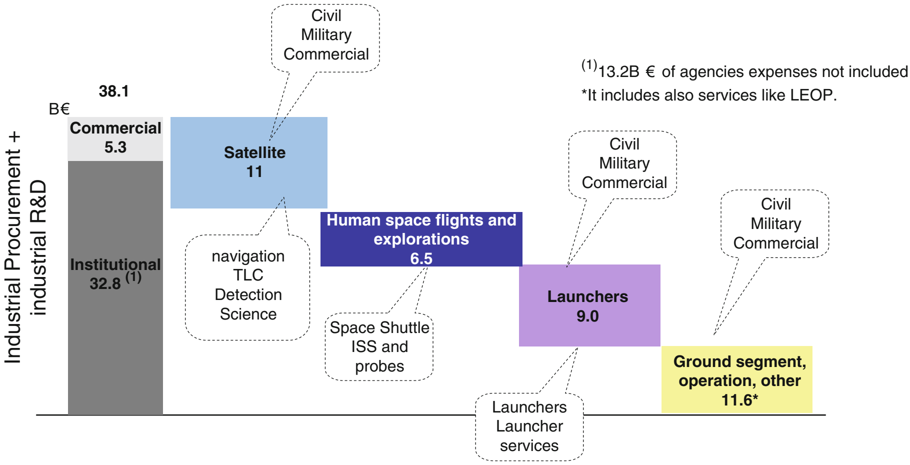


Figure 1.46. Analysis of industrial "*procurement*" in 2008. (Press release source, Finmeccanica SpA elaboration source).

This constitutes a high competitive factor for European industry, which unlike the USA's market does not benefit from an established military market that can provide adequate stable support.

For example, in the launcher sector, commercial supply from the Ukraine, Russia, and India of vehicles at low cost, even though less reliable at times, is a very competitive factor for the European Ariane launcher.

The American industrial sector is essentially the world leader, followed by Russia, China, and Europe.

China is becoming an emerging power even in the space sector and after sending men into space has clearly surpassed Europe in industrial capability. However, this does not mean there is a lack of competent industrial capability in Europe but rather a lack of funding dedicated to this sector.

India is an autonomous space power that can realize satellites and launchers and is emerging on the commercial market. Canada has developed a significant space industry that benefits from excellent relations with both the USA and Europe. Japan has developed a major industrial sector centered on scientific research and planetary exploration. Israel has developed autonomous capability for realizing telecommunication and Earth observation satellites for defense purposes.

In conclusion, the space market is undergoing significant development and an increasing number of countries are developing satellite tools for establishing an industrial base, which can provide them with strategic industrial capabilities.

Figure 1.46 presents an overview of the volume of estimated business for so-called industrial *"procurement"* for 2008, the value of orders acquired from the major industries for the sector, while Figure 1.47 illustrates the turnover of the *Prime Contractors* in 2009.

Figure 1.48 presents the 2009 turnover from major second-tier companies (main *Sub-Contractors*) of the manufacturing pyramid, that is, the ones that can supply subsystems integrated to the "*Prime Contractors*."

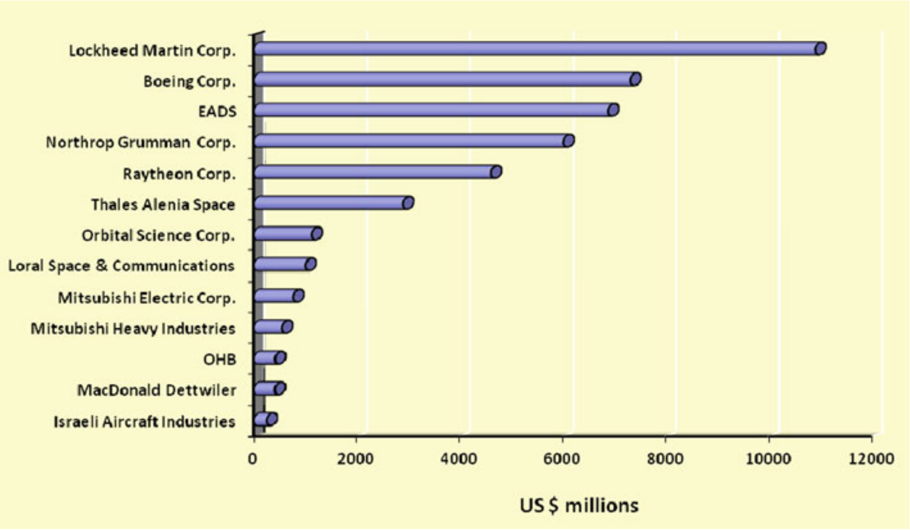


Figure 1.47. Turnover in 2009 of the major space manufacturing Companies—*Prime Contractors*—. (Press release source, Companies Annual Reports source, Finmeccanica SpA elaboration source).

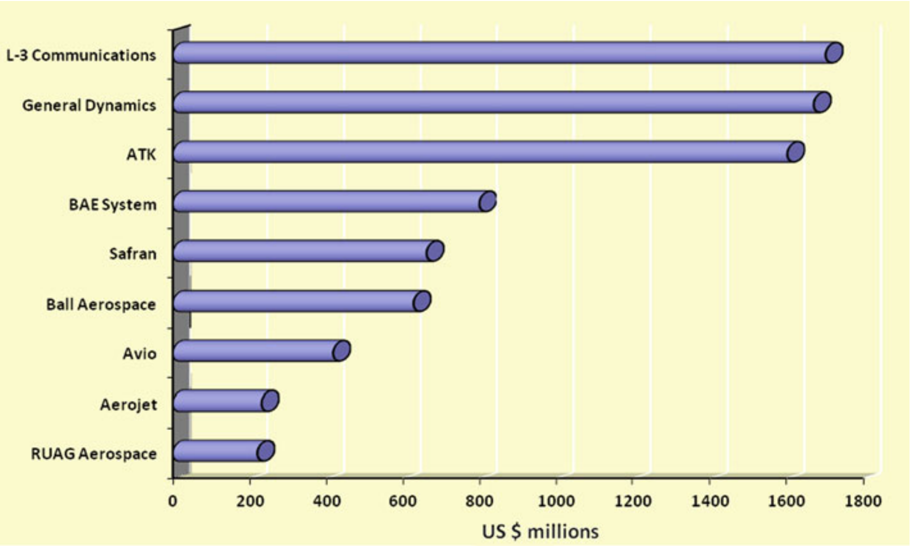


Figure 1.48. 2009 turnover of major manufacturing companies, suppliers of subsystems to the *Prime Contractors*. (Press release source, Companies Annual Reports source, Finmeccanica SpA elaboration source).

However, we can analyze the competitive position of the main "*Prime*" companies that goes beyond the above numbers of business volume to describe the world industrial manufacturing sector.

Figure 1.49 illustrates how (with the exception of two companies) almost all global *Prime Contractors* operate within the institutional market for most of their

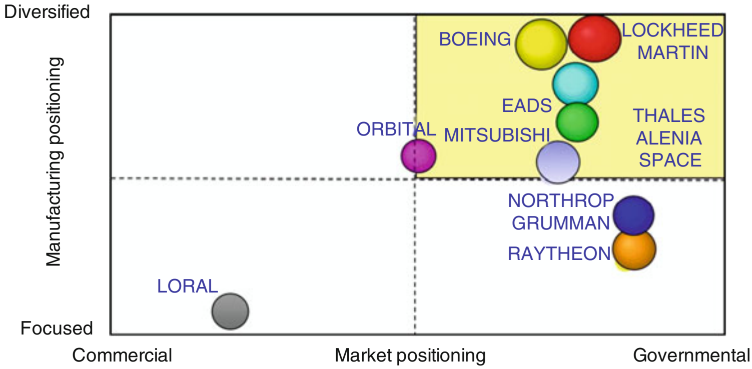


Figure 1.49. Positioning of global "*Prime Contractors*" on the market/product grid.

returns; this does mean they are not present on the commercial market but only that their production nature is linked more to government programs.

The figure also shows how the only companies with a purely (or for the most part) commercial value have a specific product focus. Loral Space & Communications, for example, only produces one type of telecommunications satellite it sells to commercial operators throughout the world.

The main *Prime Contractors*, on the other hand, have a variety of products and therefore a varied product offer, from satellites to launchers to space infrastructures.

The current industrial scenario is the result of a series of mergers which occurred in the 1990s and 2000s, which reduced the number of "*Prime Contractors*" by about 30 to only 10/12 companies in the world and the merger process is probably not over, especially in Europe.

The Services and Applications Market

Space services are based on the use of telecommunication, Earth observation, and radio-navigation and localization satellites, in addition to scientific services from space science missions.

Satellites on which the supply of services is based are almost always complex and costly and operators are usually civilian or military institutions.

However, a bustling market for satellite services has developed in telecommunications and many operators have developed in the world, for the most part private or as a result of privatizations, which offer satellite linkup for telephones, television, or data exchange on the market.

In the Earth observation sector, public operators dominate, while in positioning and navigation there has been a true boom in GPS terminal diffusion for automobile or private use (e.g., mobile phones).

Scientific missions, on the other hand, are public in nature and are government funded.

Therefore, space services can be subdivided as follows.

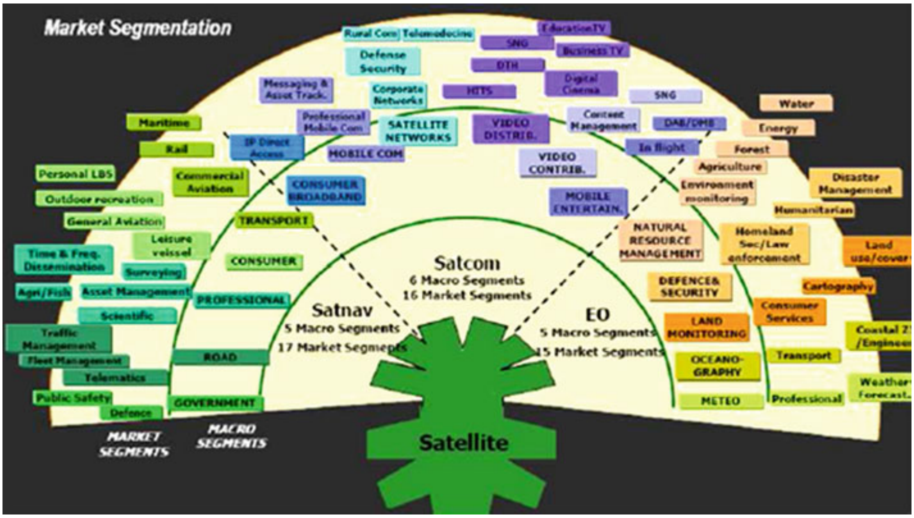


Figure 1.50. Functional segmentation of the satellite services market. (ESA source).

Basic services

- Of *telecommunication*, which supply linkup and network elements for TV and TLC segments
- Of *Earth observation*, which supply information and data relative to observation and monitoring of ground phenomena through space infrastructures
- Of *positioning and navigation* which supply elements for localizing objects on the Earth's surface or in flight through space infrastructures
- And *control and management of satellite and mission systems* for operating ground space infrastructures

Value-added services which by combining one or more linkup elements, monitoring and localization, provide the final user with integration information on items of interest.

The essential components for providing services are:

- Satellite capability, that is, the possession of satellites or at least access to the competences of integration and management of networks and data
- Competences for the development of applications based on information generated by space systems

Value-added services can be segmented according to the type of dedicated satellite platform and their final target markets.

More developed and emerging services are at any rate the result of the combination and use of all types of satellite platforms.

Figure 1.50 illustrates a functional segment of the market for satellite services; while Figure 1.51 presents an economic segmentation of the satellite services markets (GPS navigation market is not included).

In the services market, we must also consider the volume of business generated by the sale of ground terminals that can vary from antennas for receiving data, both for

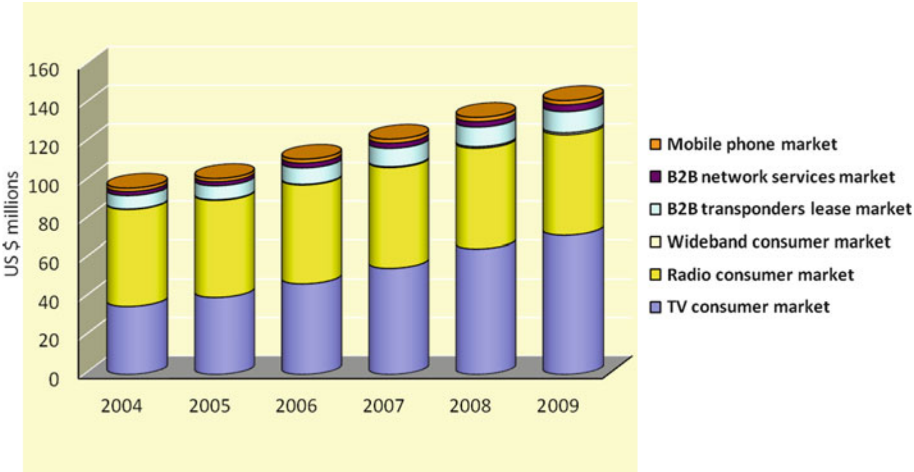


Figure 1.51. Economic segmentation of the satellite services market. (Satellite Industry Association web site source).

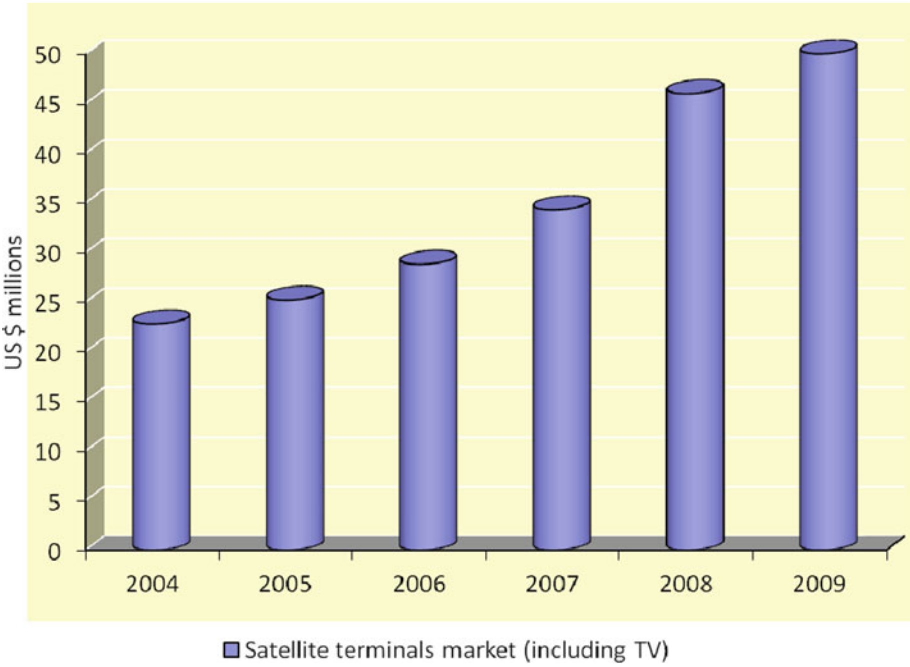


Figure 1.52. Market turnover for the sale of satellite terminals. (Satellite Industry Association web site source).

family and business use, to GPS terminals for automobile and personal use (receivers incorporated into mobile phones).

Figure 1.52 therefore describes the development of world business volume for the sale of satellite terminals.

In the telecommunication sector the world global market is characterized by oligopolies. There are few global operators (SES Global, Intelsat, and Eutelsat) and many small operators on local markets.

Figure 1.53 presents the turnover of the major satellite telecommunication operators in the world, including several companies active in manufacturing terminals (e.g., Garmin, Gilat, and Viasat). In fact, Garmin, which is the first, realizes hardware and terminals for GPS receiving systems, but does not operate a fleet of satellites as does instead Intelsat, SES, and Eutelsat for example.

Figure 1.54 shows how 61% of the transmission channels offered by geostationary satellites are owned by the first four world operators, while the remaining 39% are owned by local operators distributed in regions (e.g., Russia or East or South Asia) where the first four are less present. However, basic data show that, compared to the first years of the 2000s, there are many more commercial operators today.

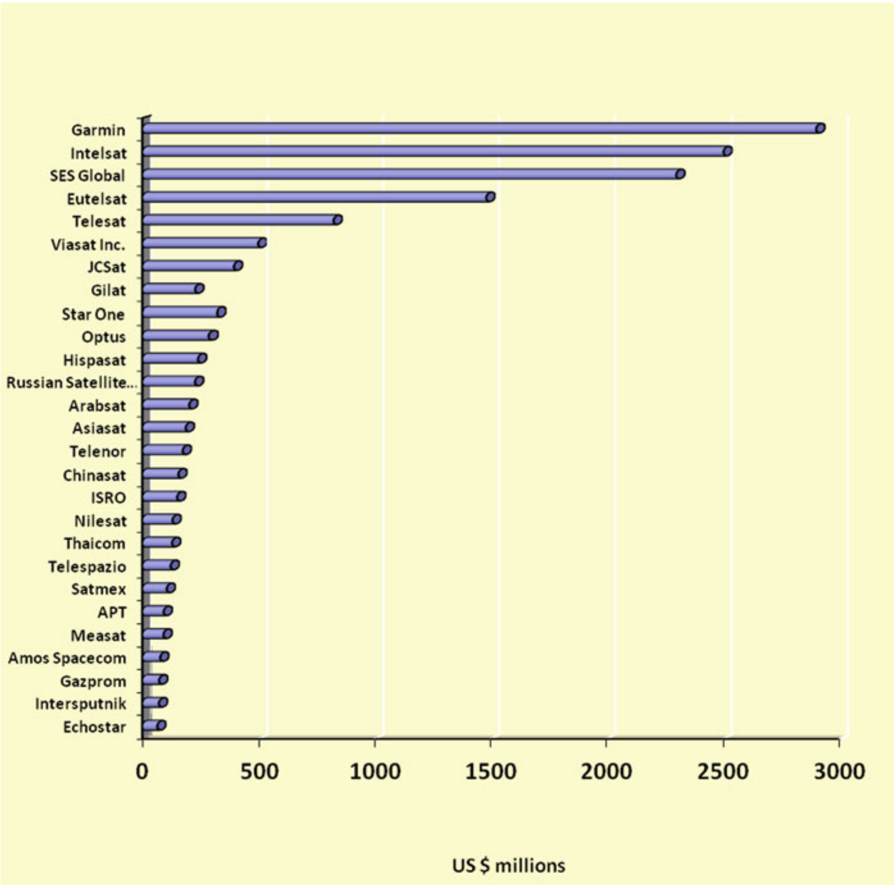


Figure 1.53. 2010 turnover of major telecommunication satellite operators. (Press release source, Companies Annual Reports source, Finmeccanica SpA elaboration source).

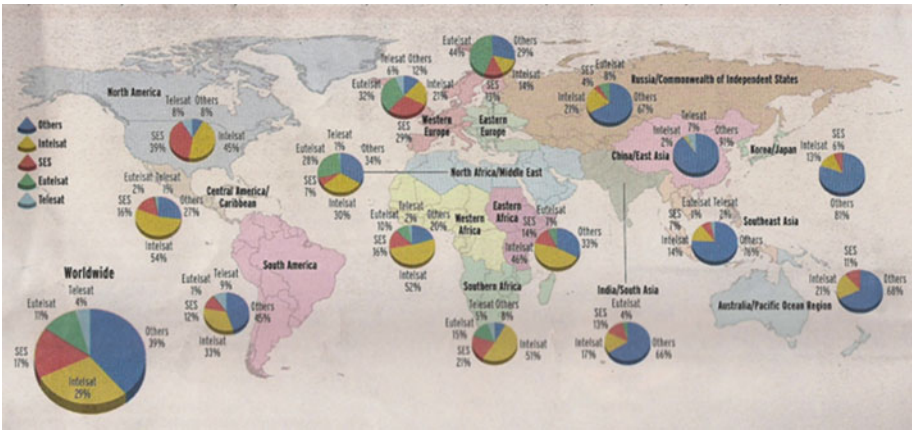


Figure 1.54. Geographic location in 2010 of the major telecommunication satellite operators. (Space News July 2011 source).

Terminals in Service (Millions)	2008	2009
Satellite TV	133.6	141.3
Satellite Radio	20.4	20.5
Mobile Satellite Services	1.9	2.0
End-User Broadband	1.0	1.1
Mobile Satellite TV	1.3	1.5

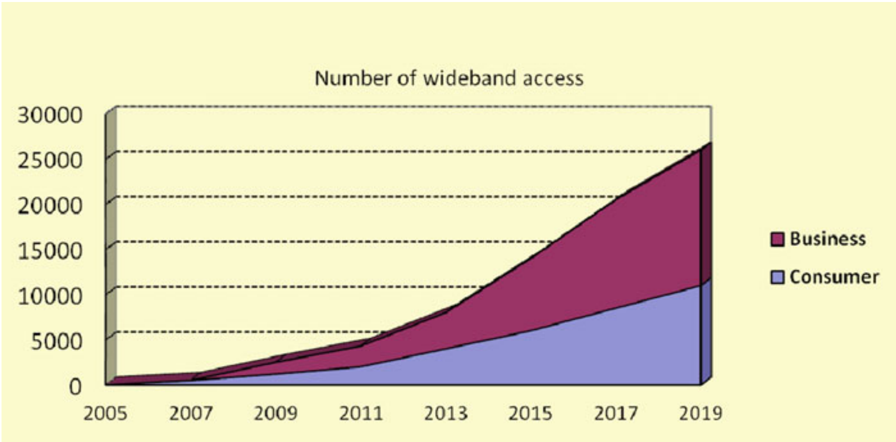
Figure 1.55. Development of the number of telecommunication terminals. (Satellite Industry Association web site source).

Concerning ground terminals for telecommunications, Figure 1.55 shows the development of business volume for use sectors, highlighting how satellite TV is the major global market and with the best outlook for development, thanks to the diffusion of high-definition television, which requires a broader bandwidth for broadcasting and therefore greater satellite capability.

The satellite communication market remains a vital sector and the outlook for growth in new services indicates high levels of growth, as illustrated in Figure 1.56 concerning broadband network ground access services, as well as maritime communication services.

In the sector of Earth observation instead, few operators, mainly American and European, compete in a market that is essentially institutional and oriented toward defense, but with growth potential even in nonmilitary sectors that drives many nations to invest in dedicated space systems.

In Italy, for example, the Cosmo-Skymed system has made a great amount of data available since 2010 and radar images that provide new generation of applications.



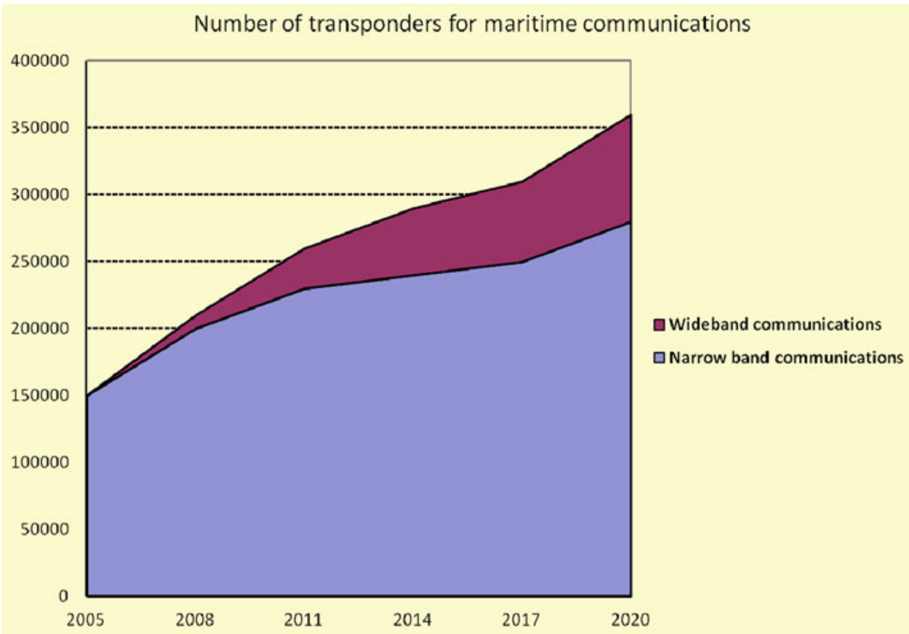


Figure 1.56. Forecast for the development of returns for new telecommunication services. (Press release source, Companies Annual Reports source, Finmeccanica SpA elaboration source, Aviation Week March 7, 2011 source).

REGION	OPERATOR	SATELLITE	INSTRUMENT
North America	Digital Globe Inc.	World View 1, 2 Quickbird	Optical, high resolution
	Geoeye Inc.	Geoeye 1, Ikonos	Optical, high resolution
	Landsat.org	Landsat 5, 7	Optical, medium-low resolution
	MacDonald Dettwiller	RadarSat 1, 2	Synthetic Aperture Radar, medium resolution
South America	INPE	CBERS 2B	Optical, low resolution
Europe	Sovzond di Roscomos	Resurs DK1	Electro-optical, high resolution
	Rapid Eye AG	Rapideye 1, 2, 3, 4, 5	Optical, low resolution
	Astrium Services	Spot 4, 5	Optical, medium resolution
	QinetiQ	TopSat 1	Optical, low resolution
	DMCii	UK-DMG 2G	Optical, low resolution
	e-Geos	Cosmo Skymed 1, 2, 3, 4	Synthetic Aperture Radar, high resolution
	Infoterra	Terra-SAR X	Synthetic Aperture Radar, medium resolution
Asia	Antrix	CartoSat 1, 2 Risat 2 ResourceSat 1	Optical, medium resolution
	JAXA	ALOS, ADEOS-2, JERS	Synthetic Aperture Radar, medium resolution
	KARI	KompSat 2	Optical, low resolution
	NSPO (Taiwan)	FormSat 2, 3	Optical, low resolution
Middle East	ImageSat Int.	EROS A1, B, TecSar	Optical, medium resolution Synthetic Aperture Radar, medium resolution
Africa	DMCii	NigeriaSat, Altsat	Optical, low resolution

Figure 1.57. Major operators of satellite imaging in the world.

Figure 1.57 shows us a list of the main satellite imaging operators in the world.

Included among these, we see only the two American operators, Geoeye Inc. and Digital Globe Inc., had returns in 2010 a little over 300 million USD, while the other companies generally have returns less than 10 million. This is due to the number and type of satellites available in order, which is to the resolution of the remote sensing instrument.

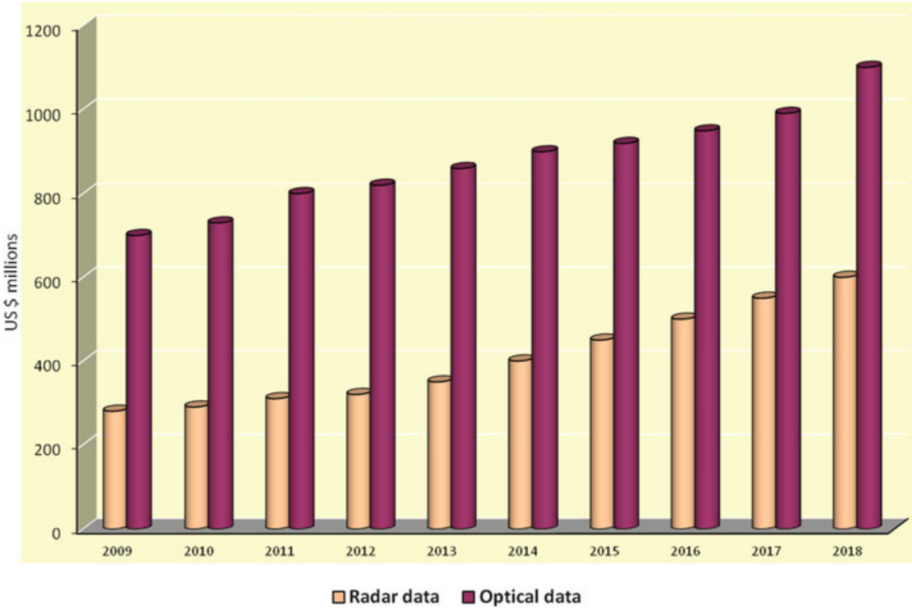


Figure 1.58. Estimated 2009–2018 sales of satellite images. (Press release source, Finmeccanica SpA elaboration source).

Figure 1.58 shows an estimate of the promising market from the sale of satellite images in the near future, which includes commercial sales and sales for government use, of optical and radar images.

In the navigation and info-mobility segment, the main target markets remain aeronautics and personal mobility (automobiles and mobile phones). The entrance of third-generation GPS satellites into service, the European Galileo satellites and the renewal of the Russian Glonass fleet should lead to a substantial reduction in costs for devices and related services. Moreover, it is foreseen that the new guidelines of the European Union for standardization of the specifications will allow the targeted markets to take off.

The market trend for the SOP sector (Satellite Operators), which includes putting commercial satellites into orbit and their maintenance, has been forecast as being stable for the future, while new opportunities for managing the satellite fleets for “dual” use are predicted.

Chapter 2

Space Program Management

Program management has to ensure the success of a project, and therefore this is the main objective of the management team. Success is based on the industrial project and on maintaining commitments made in terms of cost estimates, maintaining time schedules and achieving results.

Program management involves all the methods and tools of project management. It can be defined as a vast range of human expertise. This book limits itself to space projects, which, due to their special nature, are essentially complex and of long duration.

The mistake most often made is thinking that management methods and tools can be acquired during the development of the project itself. This almost always leads to estimation errors and has a negative impact on the program.

Since ultimately every industrial program is essentially a human activity, and humans are at the center of the "man-technique-market" trio which pervades a project, and for this reason these management techniques evolve with man's social, industrial, and behavioral development.

Therefore, management is not an exact and unchangeable science. Generally, it can be broken down into four basic types of actions:

Planning: These activities are aimed at studying and preparing documents for establishing objectives and requirements within expected time frames. Afterwards, development plans are communicated.

Organization: These activities are aimed at adapting production structures to achieve objectives, to divide work into subsystems to reduce the overall complexity of the project, and to make work efficient.

Coordinating: These activities are aimed at directing, informing, and communicating within the structures involved, coordinating work and providing motivation.

Control: These activities are aimed at establishing rules and procedures which measure the results achieved through time so that there is an awareness of possible differences between what was achieved and what was expected to be realized at that time (Figure 2.1).

M. Spagnulo et al., *Space Program Management: Methods and Tools*,
Space Technology Library 28, DOI 10.1007/978-1-4614-3755-0_2,

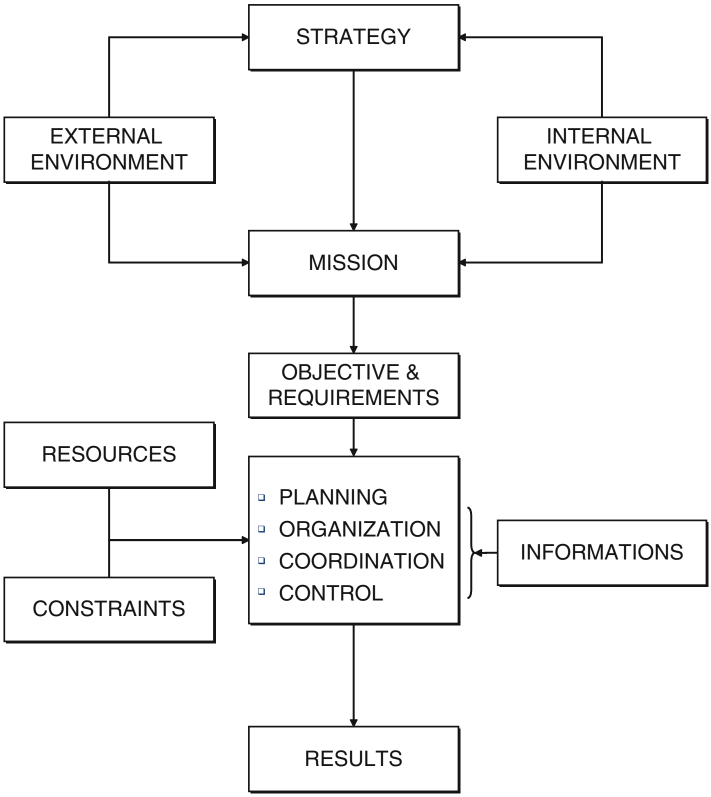


Figure 2.1. Basic management methodology flowchart.

2.1. Characteristics of Space Programs

For the most part, a space program is a major project for:

1. The development, realization, putting into orbit, and use of space systems, such as satellites, scientific satellites or orbiting infrastructures, with the aim of fulfilling the aims of the mission for which the systems were designed.
2. The development, realization and testing in flight of a launch system (i.e., a space launcher) which can put a payload (i.e., the space system referred to in point 1) into orbit.

Therefore, a space program has specific characteristics based on the type of mission to be performed. These characteristics influence the specifications and decision-making process involved in the realization process from its conception.

It is important to define a space program through an analysis of its main characteristics which can be summarized thusly:

- Strategic importance
- Extent of international participation
- Specific industrial and specialized sector
- Significantly high investment cost

- Long-term time frame program
- Rapid development, obsolescence, of the technologies used
- Impossibility of intervening in space for repairs and/or maintenance
- Use, which is often incorrectly understood and scarcely perceived outside of the framework of the specific sectors

Strategic Importance

The space sector, in addition to civilian applications, is unquestionably linked with military requirements and applications because of its history and constant technological development advancement.

The ability of satellites to fly beyond borders and their ability to connect people in different continents without using on-ground infrastructures are only two of the many reasons for their strategic and military features.

A nation's capability, or a group of nations such as Europe, to be able to design, realize, and launch space programs is an essential requirement in the third millennium in order to be respected politically and economically at the global level.

This capability is expressed in two technological areas: autonomy of access to space (ability to use one's own launcher from their homeland) and satellite technology availability. This can be traduced in having an industrial sector capable to design and build autonomously launchers and satellites platforms, as well as electronics on-board. Without this technological autonomy, a nation cannot consider itself a space "power."

Extent of International Participation

Quite often, because of its industrial and economic scope, a space program is implemented in the framework of international cooperation. In addition, a space program operates in extra-atmospheric space and therefore the entire human community can be involved both negatively and positively.

It should be pointed out that when space technologies began in the 1950s and 1960s, the programs were developed exclusively on a one-nation basis, in the USA and the former Soviet Union. Since there was a strategic, political, and military competition between the two blocks (West and Soviet) behind all programs, space was mainly a theater for tactical confrontation.

There has always been a spirit of collaboration among nations since the 1960s in Europe and the creation of the European Space Agency (ESA) is a proof of this. The Member States are committed to creating a supranational organization charged with developing space programs for peaceful purposes, that is, for knowledge and the common good.

Obviously, ESA has not stopped the national space agencies of the major Member States, France, Germany, and Italy, which altogether have contributed approximately 60% of ESA's budget, by designing and realizing nationally based or bi-multilateral-based programs.

However, what is brought to the forefront of discussion in this book is space's international character which is not only political and dimensional, but also technical.

The international aspect is already significant during the technical definition of a space program: the fallout of a launcher's stages in the sea or on land, the reentry of satellites into the Earth's atmosphere (or the Space Shuttle), global coordination of

the use of radio-electrical frequencies for satellite transmission and reception, crowding and overcrowding of orbital spaces on local or global geographical areas, limitations on the use of onboard satellites of radioisotope power generators, limitations on the coverage from space of geographical areas with radio-electric emissions.

All of these technical aspects give a limited idea of the international characteristics of a space program.

The international aspect of a space program is very often also stressed by the need to share the high costs which cannot be afforded by single nations.

Specific and Specialized Industrial Sector

From the beginning, the realization of space systems has been the prerogative of dedicated industries which during the course of many years have developed specific competences and their own development means.

This has globally brought about the creation of an industry in the broadest sense of the word, a unit of scientific and industrial entities highly focused and specialized.

This has to some extent prevented the development of a major synergy in the past between the space, aeronautical or electronic industries. However, now there is a major transfer of expertise and resources among those areas.

There continues to be specific industrial feature of the space sector, which highly defines the specialization. For example, still nowadays CPUs derived from old technology processors are installed on commercial television broadcast satellites. New CPUs such as the ones equipping home or office computers could be much more efficient; however since they must function in extra-atmospheric conditions, the qualification and testing process is such a high-level and specialized requirement that the industrial specificity has been maintained and is evolving slowly.

Significantly High Investment Cost

A space program's cost is always a major investment, whether it is funded by public funds or private capital.

In the first case, investments come from space agency's budgets, while in the second case the capital is from commercial and private companies that are investing for a profit.

For example, let's examine the Ariane 5 program, selected by ESA in 1985. This program was supposed to conceive and realize the European launcher of the twenty-first century. When it was first launched in 1996, the program had cost 6 billion euro and had been completely funded by ESA with public funds. Since the first launch failed, more years and billions of euro were needed to achieve a testing configuration of the launcher during the first part of the 2000s.

The initial decision to undertake these programs, however, was full of not easily foreseeable consequences and could only be taken at the highest level of government. In fact, the highest decision-making body for ESA is the Ministerial Council where the Research Ministers of the Member States are seated and commit their respective governments with their decisions to fund ESA's programs on a multi-year basis.

On the other hand, decisions are taken by the Board of Directors of the companies which intend to start up a space program for profit in the case of private commercial concerns.

This is why the manufacture, launch and operations of a television broadcasting satellite can last 15 years and can cost a minimum of 200 million to a maximum of 500 million euro, depending on the satellite's size and the number of transponders it contains.

Another example is the private commercial initiatives involving telephone communications satellites that were realized in the 1990s, Iridium and Globalstar for example, which cost private investors up to 9 billion euro.

The large amount of investment required is because a space program is so complex that it involves many partners at all levels and requires specialized industries which only five or six countries in the world possess.

Long-Term Time Frame Program

Generally, it takes more than 10 years between the first preliminary studies on a space system and the end of operational services and sometimes, in the case of launchers or the International Space Station (ISS), even more than 20 years.

Sometimes the development of satellites, for example European weather satellites, can last 20 years before evolving to the subsequent generations. The American satellite system Global Positioning System (GPS) for navigation and localization, began its first feasibility studies in the 1970s and became operational during the first war in the Persian Gulf in 1991. In 2008, the American Defense Department began the development of third-generation GPS satellites to ensure both the renewal and evolution of the system.

From these and other examples, the importance of outlook and vision when undertaking a space program is understood. This is also necessary because sometimes it is difficult to be aware at the start-up of broader uses of the system.

Rapid Development, Obsolescence, of the Technologies Used

The technologies used for space programs have evolved extraordinarily in the last 40 years. Astronauts of the Apollo Moon missions of the 1960s did not have the computing capability on board their spacecraft, which is now available in a Personal Communication Device, such as a notebook, or laptop or multifunction cellular phone.

The onboard software of the Moon-landing module used about 20,000 lines of instructions. Today, any smart-phone contains software with millions of lines of instructions.

For this reason the choice of technologies used in space program missions remains an exercise in caution and balance since the directions taken will influence the program during its entire operational life.

The technological level acquired at any given point in time can influence the choice of a space program in at least two obvious cases:

- A technology which is not immediately available but only after a research and development phase could be a handicap to the development of well-identified applications.
- On the other hand, a technological advancement could have a flywheel effect for a program with a greater future outlook for its applications.

Impossibility of Intervening in Space for Repairs and/or Maintenance

Despite the promises of the past decades to operate in space in an "ordinary" way, this is still not the case. Therefore, 99% of the time it is impossible to repair a breakdown which occurs while the satellite is in orbit.

The remaining 1% possibility is for very special missions such as NASA's Hubble space telescope which was repaired in orbit by American astronauts. Once they reached the Space Shuttle at over 600 km in altitude they repaired it, performing the necessary modifications to restore focal balance to the lenses, every 8 or 9 years. However, the mission was complex and costly and was only carried out because Hubble's orbit could be reached and it cannot be overlooked that billions of dollars invested by NASA would have been wasted once the focusing defect of the lenses was noted soon after the start-up of the space telescope's operation.

Obviously, this case is quite out of the ordinary, in addition since the Space Shuttle has been phased out in 2011 no one will reach the Hubble Space Telescope anymore.

In the case of commercial telecommunication satellites which orbit at 36,000 km altitude, any attempt at repair or maintenance to date can theoretically be done but operationally has never been developed.

Minimizing breakdowns is reduced with in-flight experience of pre-operational satellites or during testing, whenever possible, in order to learn how to improve the production process on ground.

Use, Which Is Often Incorrectly Understood and Scarcely Perceived Outside of the Framework of the Specific Sectors

Despite the growing importance of the uses derived from space systems in the last 40 years, the potential benefits from this sector often remain misunderstood not only by a large number of people who are not involved in making them, but also sometime by politicians in charge who are ultimately the ones to decide on the amount of public investment to be made in the sector.

In several sectors such as telecommunications or weather satellites, the use of satellites has become an integral part of the means used by public institutions or businesses and the public realize their need because of the direct advantage they benefit from (for example, satellite pay TV used by millions of European citizens and the world know the advantages of satellites).

The recent boom in the spread of GPS satellite navigators for cars and cellular phones has further drawn the public to an awareness of the use of space systems, but many of them still do not understand their use.

Space systems for Earth observation, for example, whose technological development is constantly growing, are certainly understood and used by public institutions such as military authorities, but other government agencies still do not know they could use the services provided by these systems for managing the territory, coasts, agriculture or for other socially useful aspects.

Space systems for cosmology or the study of the universe have always fascinated the public because the discoveries they make have the magic of bringing man closer to the fascinating mysteries of the stars and planets. Too often, however, this fascination is only accessed sporadically at the time of a certain media event which will remain locked in the restricted circle of the scientific community. It is also true that

the scientific discoveries of space systems of the past 30 years have allowed us to revolutionize and broaden our knowledge of the solar system as man has never been able to do in the past centuries.

An age-old debate on whether or not to develop programs with astronauts to orbit around the Earth, towards the Moon or Mars, rather than send robotic probes is also part of this misunderstanding of space programs.

The most widespread obstacle concerns the fact that beyond the strategic or political needs of a nation to affirm their own technological superiority by sending men into space (which was the basis for NASA's Apollo Moon program), there have been no significant technological advantages or knowledge to date on sending men into space compared to the enormously less expensive achievements of satellites or robotic problems.

There is no one clear answer to this debate which remains animated but incomplete, and certainly space agencies should make an effort to spread knowledge about the space sector to the greater public, but with an awareness of the possible advantages of these technologies, as well as their limits, it has the unknown elements and risks which are present in many other human activities.

2.2. Methods of Defining and Managing Space Programs

Because of its nature and obvious destination, a space program is aimed at realizing a space mission.

The necessary industrial products to be realized for this are:

- Launchers, either reusable and expendable satellites or space probes.
- Space infrastructures, such as the ISS.
- Orbiting vehicles, such as, for example, ESA's Automated Transfer Vehicle ATV.
- Space planes, for example Scaled Composite's SpaceShip which Virgin Galactic intends to commercialize tourist flights in the first layers of extra-atmospheric space.

Because of its size, a space program is generally an industrial program whose realization is the result of many technologies which altogether form a *system*, built by many industrial participants who make up an *industrial group*.

In complex space programs, the industrial group is then legally and industrially represented by a sole industry called the *Prime Contractor* which becomes the only interface with the customer to supply the product.

The combination of these two components which characterize a space program makes for a generally complex and risky enterprise, whose costs and duration have highly variable project parameters despite estimates and accurate forecasts during the design phase.

Clearly, these two parameters are intrinsically related not only to technological but also to the political, strategic, and economic aspects of a space project.

Every space program is divided into two macro areas for its development and operations:

1. The space segment
2. The ground segment

The space segment is physically the vehicle which flies into space; the ground segment is made up of equipment on ground during the operational life of the program for use on the space segment (for example, reception terminals for television programs or satellite navigators for cars), or to control spacecraft (for example, satellite stations for telemetry and remote control).

The link for realizing the two segments of a space program is the system activity.

Therefore, the term system can be broadly defined as the capability of managing the realization of a space program through engineering and is an essential component for already multiple competences required ranging from technical to economic and even human resources.

2.3. Implementing Space Programs

A space program includes two main phases and a start-up decision is taken in the middle of the program:

1. The phase at the beginning: identification and conception of the mission, including the analysis of products/technologies to be used and the various cost/time estimations.
2. The phase after the decision: the development and installation of the system.

Program Definition

In the first period the mission is identified and therefore the requirements to be satisfied are drawn down (for example, the realization of a new cryogenic propulsion motor to increase the performance of a launcher to maintain competitiveness on the market).

In the first phase it is crucial to identify the preliminary project, that is to say the conception of space technologies/products to use, if in existence, or to be developed, if they are not available, to implement the mission.

In Figure 2.2, an example of requirements matrix is given which basically reports the subsystems and essential systems to be considered during the processing of the preliminary project.

The starting point is a preliminary industrial project to implement a program, i.e., the analysis of a development plan of a mission which identifies the necessary products, associated risks, available technology and technology to be developed (which enter into the associated risks category), industrial competences to involve, estimate of development time and realization costs.

The decision-making context for implementing the program is therefore essential. The most wide-ranging political, economic, strategic socio-cultural, industrial and scientific and other factors can influence the decision whether or not to start up a space program, be it government-funded or commercial.

In each case, once the elements of the project and the decision-making context are analyzed, what happens next is the negotiation phase, i.e., the phase needed to convince the customer to decide to invest in the program.

Generally, innovation is almost always essential for the positive acceptance of a space program and an innovative mission can fulfill new needs and requirements such

	LAUNCHERS	SATELLITES	SPACE MANNED ORBITAL STATIONS	MANNED REUSABLE SPACECRAFTS	SPACE UNMANNED ORBITAL VEHICLES
SYSTEM					
System engineering	■	■	■	■	■
Project control	■	■	■	■	■
Quality assurance	■	■	■	■	■
Integration & Test	■	■	■	■	■
Operations	■	■	■	■	■
GROUND SEGMENT					
Operations	■	■	■	■	■
TT & C	■	■	■	■	■
Logistics	■	■	■	■	■
Maintenance				■	
SPACE SEGMENT					
Structures & Mechanism	■	■	■	■	■
Aerodynamics	■			■	
Thermal	■	■	■	■	■
Aerothermal	■			■	
Propulsion					
Navigation				■	■
Guidance	■			■	■
Control	■	■	■	■	■
Orbital Attitude Control		■	■	■	■
Power Generation					
Fotovolthaic		■	■	■	■
Chemical	■	■	■	■	■
Thermal			■	■	■
Power Supply	■	■	■	■	■
On Board Computer	■	■	■	■	■
TT & C	■	■	■	■	■

Figure 2.2. Example of requirements and needs matrix.

as increasing already existing availabilities in order to reach new levels of technology (for example, increasing a launcher's performance through the introduction of new propulsion technologies). On the other hand, however, the innovation component is also the bearer of future technological development risks and use risks.

For example, the realization of an onboard antenna for a large low-frequency satellite, over ten/fifteen meters, can be a commercial advantage for the future managers of the satellite in terms of greater number of users who can be reached by the service. However, it could also cause delay risks in the development or worse yet, malfunctioning during its operational life if the antenna technology has not been previously tested by the industry called upon to realize it.

Since a space program is frequently the original integration of new technologies, its success depends on the correct definition of the mission's specifications which must be applied in an extremely accurate manner. Its success also relies on the correct identification of industrial products to be developed whose technologically innovative contribution must be appraised carefully and realistically through the forecast of development risks. It also depends on the correct definition of the program's organization, its duration and costs.

The process which identifies levels of technological risk with the use of products/components of a space system is called "TRL scale" where TRL is the acronym of "Technology Readiness Level." TRL is a methodology for measuring the technological maturity of a component or product, including the final subsystem element. This measurement is essential for understanding the level of technological risk to which the system is subject.

The TRL scale is made up of nine levels:

TRL 1: Transition of a system derived from pure scientific research to application research. Describes the essential features of a system in basics through mathematical formulae or algorithms.

TRL 2: Applied research. The theory and basic scientific principles of technology are focused on an application area and the analytical instruments for simulation are developed.

TRL 3: Validation of "proof of concept," testing a model of the system to be realized is functioning. Research and development are implemented with analysis and laboratory studies. Technical feasibility is demonstrated by developing models whose representation of the final product is still incomplete.

TRL 4: Realization of prototypes and tests. Testing is therefore performed on scale models that are almost fully representative of the final one.

TRL 5: Validation of the integrated prototype with verification testing of the specifications in an environment which represents the future operational environment as much as possible.

TRL 6: The prototype is developed in "full-scale" and the engineering feasibility is tested with application tests that represent the operational environment.

TRL 7: The prototype is tested in an operational environment (or highly realistic one) with a detailed series of tests. The documentation of the technology produced assumes an established form with the corroboration of testing.

TRL 8: A qualified flight system through testing or demonstrations in operational environment (on ground or already in space). The relative documentation is complete both for training and for eventual maintenance.

TRL 9: The so-called "mission proven" system—that is, already used in operational and application environments in space and has demonstrated its effectiveness with a successful operational experience.

The TLR scale is therefore essential in defining the program since it allows us to determine which and how many products, components or subsystems to be used could need innovative developments or not.

Just as important is the preliminary evaluation to measure of integration of the final system to be realized. Whether it is a satellite, a launcher or a robotic system to be sent to another planet, or even a technologically relevant subsystem, the measurement scale

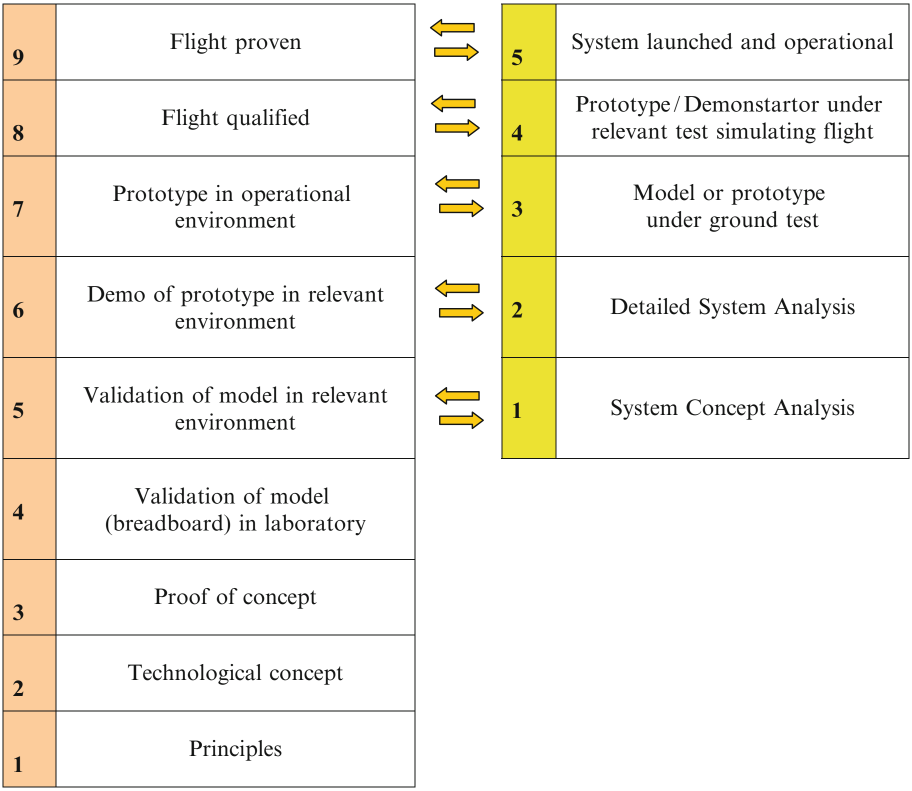


Figure 2.3. Comparison of the TLR and ILR scale.

of the IRL—Integration Readiness Level—supplies an important instrument for understanding the level of difficulty connected to realizing the determined system.

In the same way as the TLR, the ILR also is made up of various scales—five—which indicate the degree of technological confidence:

ILR 1: corresponds to a system where the concept of the whole has been completed
ILR 2: corresponds to a system where the detailed project has been completed
ILR 3: corresponds to a prototype (or a demonstrator called a mock-up) subject to on-ground testing
ILR 4: corresponds to a prototype (or a mock-up) subject to testing simulating flight
ILR 5: corresponds to an operational system, manufactured and already launched

NASA, which introduced the ILR level concepts in 2002, then began modifying them to arrive at a scale of 9 ILR, forming a metric standard called SRL or System Readiness Level which is still in consolidation phase.

Figure 2.3 shows the relationship between the TLR and ILR scales.

Just like most industrial and economic operations, even the development of a space program must, directly or indirectly, lead to an economic objective, such as a return on investment. This is obviously true for private programs with financial objectives, such as commercial telecommunications missions, but generally speaking the same principle should hold true for publically funded space projects (such as the ISS).

More realistically, in these cases very often the objective is mainly industrial strategy and government geo-policy, in which case financial objectives are not necessarily the priority. This leads to undertaking technological risks which are often a characteristic of the agency government programs.

Realization of the Program

In the second phase of realization and implementation, there are the activities related to:

- Negotiation and signature with the customer of a contract in which the customer carefully establishes the objectives to be achieved to the industrial group or Prime Contractor.
- Definition of a document called the "Management Plan," which is a reference guidelines for the program manager for all development levels, the realization, the implementation and the achievement of the objectives established by the contract.
- Management, which is a dynamic and continuous activity of control and guidance of various development phases.

The contract is signed after negotiation between the industrial group and the customer standing a technical-economic proposal by the group. This proposal usually follows a request for proposals, drawn up and sent by the customer to various potential suppliers.

The contract establishes the objectives which are:

- Technical: observance of specifications, external interfaces, performance and quality of the product to be supplied.
- Temporal: observance of delivery time indicated in the contract during all realization phases.
- Financial: observance of costs indicated in the contract and payment plan which normally follow the time delivery plan.

Should one or more of the objectives not be achieved, whether it be the final delivery or the intermediate one, the contract generally includes a penalty to the industrial group. Generally, these penalties are financial in nature and are incurred when these three objectives are not reached.

Technical noncompliance, failure to observe one or more of the technical objectives of the contract, leads to delays in delivery and cost overruns, which are extra expenses for achieving satisfactory objectives. The costs not included in the contract are monetized by the customer as a reduction of the final cost, or if the final cost does not vary, the industrial group must bear the cost. If the Management Plan has not adequately foreseen, the financial objectives of the industrial group, the program will be negatively affected.

Time noncompliance, which is the delays in the delivery schedule, do result not only from technical noncompliance, but also from a lack of supplies or the inadequate estimate of development time. In each case, the financial fallout will result in a reduction of the final price paid. Financial noncompliance obviously includes the cost overruns caused by the two noncompliances just mentioned.

As stated previously, if the customer does not accept variations to the contract, with possible industrial compensation on the customer's other programs, the industrial group must take on the cost overruns.

However, if technical noncompliances, being one or more of the technical objectives indicated in the contract, are a result of the customer's modifications and not foreseen in the contract, then the contract is renegotiated and monetized as an increase in the final price.

In addition to the contract, the other main management tool is the "Management Plan," which is the reference document for developing and realizing the program. Every space program requires for almost all its elements, a demonstration of progress with time, on ground and a complete compliance of the product with the specifications of the contract and in general with its space mission.

These demonstrations are theoretical, that is to say numerical analysis and simulations, and representational, and achieved through bench tests.

Both types of demonstrations represent for the entire space program lifetime, tests for implementing the product which once it reaches space cannot be changed, maintained or repaired should it fail to perform properly (except for variations in software which can be modified on ground).

This development approach is laborious and systematic in a space program and must be specified in the Management Plan since the product's functions cannot be reproduced on ground under the same conditions it will be required to operate. Practically speaking, you cannot reproduce the space environment on ground to test all the integrated system as well as the various subsystems. However, thoroughness in the quality of realization, definition and conducting of tests on ground is essential for ensuring the program's success.

The detailed Management Plan is an outcome of the technical definition of the product, the "Make-or-Buy" process of the development plan, i.e., what to make inside the industrial group or what outsource, and when to test and qualify the product.

The Management Plan is based on a three-part breakdown, whose topology must be consistent, made up of:

- A technical three, which is the technical breakdown of the overall system in subsystems and equipment.
- A contract three, which is the breakdown, for example, of the main contract of the Prime Contractor in the subcontracts of lower level suppliers up to basic-level elements.
- A timetable plan, which is a breakdown in linked phases with all the elements making up the elements, subsystems and lastly the overall system.

The elementary module of activities, named elementary Task or Work Package, is located in this last component of the Management Plan.

The Management Plan identifies the drawing up of various reference documents for each contractual stage or level:

- Specifications
- Development and Realization Plan
- Task Description
- Control Plan Quality
- Configuration Plan
- Time Schedule Plan
- Budget Plan

Management Plan

1. Introduction
    - 1.1. General Objectives
    - 1.2. Mission Objectives
    - 1.3. Compatibility matrix
2. Documentation
    - 2.1. Applicable documents
    - 2.2. Reference documents
    - 2.3. Applicable Normative
    - 2.4. Definitions
3. Program Description
    - 3.1. Program objective
    - 3.2. Technical description
        - 3.2.1. Satellite system
        - 3.2.2. Communication sub-system
        - 3.2.3. Propulsion sub-system
        - 3.2.4. Thermal sub-system
        - 3.2.5. Structural sub-system
        - 3.2.6. AOCS sub-system
    - 3.3. Functional tree
    - 3.4. Product tree
4. Organization & Management
    - 4.1. General Organization
    - 4.2. Work Breakdown Structure
    - 4.3. Work Packages description
    - 4.4. Tools for program management
        - 4.4.1. Production Control
        - 4.4.2. Quality
        - 4.4.3. Planning
    - 4.5. Schedule
    - 4.6. Review
5. Quality & Product Assurance
    - 5.1. Configuration Control
    - 5.2. Documentation management
    - 5.3. Product Assurance Plan
    - 5.4. Reporting
6. Acceptance
    - 6.1. Criteria for acceptance
    - 6.2. Non-conformities management
    - 6.3. Final acceptance
7. Cost Control
    - 7.1. General Definitions
    - 7.2. Cost Planning
    - 7.3. Control Tools
    - 7.4. Reporting

Figure 2.4. General structure of a Management Plan for a telecommunication satellite.

Figure 2.4 provides a general chart of a Management Plan for a telecommunications satellite.

With the Management Plan the program managers have at their disposal a systematic tool for controlling the progress of the program and for managing it properly with the aim of achieving the specified objectives through:

- Continuous control, also in real time, of the differences for the realization in progress, measured appropriately, and the state of development foreseen by the Management Plan at that time.
- The analysis of the reasons for these differences up to the manager level for basic equipment.
- The analysis of appropriate corrective actions, the fastest, most effective and economical for putting the means and actions into place for eliminating these differences, for example reorganizing the plan, mobilizing other resources, or using program margins.
- Updating the Management Plan for complying with development reality and phase it correctly with subsequent control.

Performance, timetable, and costs are closely linked in program management through the industry's internal mechanisms. It follows that all increases in performance or quality generate delays or cost overruns and all delays generate cost overruns.

This concept must be understood not only for realization beyond contract specifications, but also for a realization which during production seems so successful that the program managers increase its performance in their eagerness to do well.

Increase in costs is definitely the most characteristic and specific overall measure of a space program's "state of disorder."

Program Constraints

The management of a space program is carried out within a tight network of constraints, that is to say obligations and limitations which must be constantly kept into consideration by the program's managers. Several of these constraints and obligations are specific to every space mission; others are generally applicable to all space programs.

Specific Constraints

The definition of the mission and ultimately of the product conceived for its realization are determined not only by contract performance obligations of time and cost, but also by limitations on the available marginstechnically, temporally, and financially.

Margins are variations of nominal project parameters, in which a system, subsystem or device still function properly.

The consistency of these margins can be reduced under overall budget obligations; for example, an industrial group is competing with another industrial group for realizing a program. In this case, the final price proposed to the customer can be dictated by business logic for obtaining the contract and in order to reduce the prices the program's margins may be tightened.

In the absence of program margins, or with reduced margins, the management of the program on the determined objectives is almost always unsuccessful.

The technical margins are a result of the state-of-the-art technologies used in the program and of the competences acquired by the industrial group. Obviously, the greater are the two, the greater the technical margins of the program.

The lack of technical margins definitely harms the product's quality and compromises the mission's success. The development risks of the lack of margins make it difficult to forecast adequately for time and costs.

The lack of time margins (for example providing for critical equipment in the Management Plan with a 10% delay on the nominal delivery time) or cost margins (for example providing for a possible cost overrun on the purchase of critical equipment in the Management Plan) inevitably leads to development noncompliance which is generally not acceptable without downgrading the equipment supply, thereby cutting the program's development plan.

The result in any case is a highly conflicting situation between the customer and the industrial group which can have destructive effect on the program itself and can cause the failure of the project.

Moreover, the decision is to use risky technologies, unqualified or newly developed ones, for the defined mission, it is crucial to provide for appropriate margins in the Management Plan as alternative solutions which can be developed in parallel down the line or solutions using qualified technologies.

General Constraints

General limitations apply to all space programs, such as:

- The special characteristics of the space environment—the physical conditions (zero gravity, cosmic void, solar radiation)—and astrodynamic conditions (Earth's or Moon's pull).
- The characteristics of the industrial group—overall rules and processes typical of the space sector (for example, the rule of Just Return in Europe, or exclusive alliances in the business world….).
- The general application rules which concern the sector; for example, the ITAR law of the US Department of Commerce which since 1998 considers every mechanical or electronic equipment made in the USA for onboard space systems, to be an armament, limiting the purchase and use by American and non-American industrial groups.
- Social and professional behaviors. Because of their nature, space programs are frequently multinational and for this reason there are permanent problems related to national interests that do not always coincide with those of the program itself. Moreover, because of their complex and multinational nature, space programs often give way to a tendency to spontaneous disorder which is inherent to all collective human activity, especially the most complicated ones.

2.4. Start-Up of a Space Program

As already stated in Chap. 1, a space program generally has characteristics such as international size, major investments, long-term realization (more than a minimum of 2/3 years) and also long operational time (over 10 years) compared to technological developments, the impossibility of repairing in orbit and finally the need of a highly specialized industrial sector.

These elements show the importance of accurate and in-depth preliminary analyses to reach the decision to start up a space program with clear and justified reasons.

The decision-making process is generally as follows (Figure 2.5):

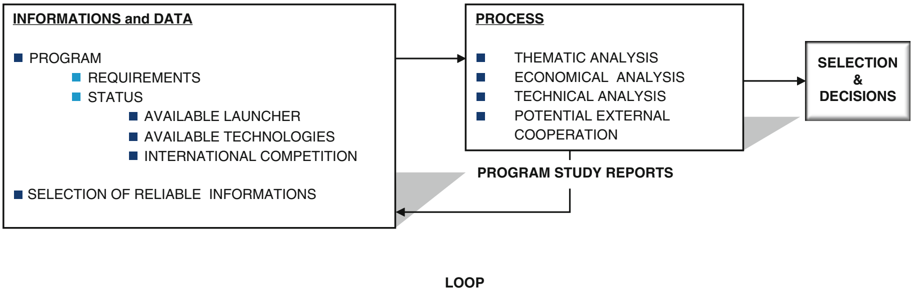


Figure 2.5. General chart of decision-making process for a space system project.

The objective is to establish a project dossier which will be presented to the decision-making bodies.

In the case of the European Space Agency-ESA, the decision-making body is represented by the European Research Council of Ministers which safeguards ESA's activities. Usually the European Ministers delegate the Presidents of national space agencies to represent them in the ESA Council for approving the programs, but every 3 years there are Inter-Ministerial meetings in which the most important dossiers are examined and eventually approved at the research ministerial level for European countries.

For private industries or mixed public–private companies, the decision-making body is the Board of Directors.

However, two main phases can be identified on the writing of the program's dossier.

Information

This involves defining the context of the program proposal:

- The requirement: basically the potential users, and the strategic and/or commercial motivations
- The state-of-the-art of potential similar programs worldwide
- The existence or not of a system/platform suitable for developing the space product
- The existence or not of an available launcher for sending into the required orbit
- The existence or not of technologies to be used
- The international and/or commercial competition
- The existence or not of potentially competitive systems, but not in the space sector (for example, satellite telephone service versus terrestrial GSM)

In this first analysis a set of information data must be reached that is complete, selected, and reliable.

Definition

It involves carrying out:

- Thematic studies, to adjust the proposed system to specific requirements of scientific or application research
- Economic studies, i.e., market analysis, return forecasts, technical studies, i.e., analysis of the project's feasibility
- Opportunity studies, i.e., strategic analysis concerning the value of the program in a commercial or political framework

- Eventual international cooperation protocols
- Obtain permission to use determined frequency bands for transmitting and receiving from and towards space

Through this process various options can be proposed to the decision-making body on the implementation of a program, the so-called "roadmap."

Therefore, a roadmap is a plan for proposing the implementation of the project. In the following paragraphs the decision-making roadmap is detailed for two characteristic types of ESA space missions which stand out because of their objectives and partially because of the decision-making modalities.

Scientific Missions

The objectives of a scientific mission is to improve the state of knowledge in a research domain, such as astronomy, the study of the solar system, Earth science, life science, and the science of materials.

But the improvement of knowledge is not easily quantifiable as a mere objective, and the evaluation of the scientific value of a program and establishment of different priorities among various missions which involve various disciplines are extremely sensitive responsibilities that must come from the scientific community itself.

The national and international scientific community is made up of professors, researchers, scientists, and industrialists and is a community of competences that have an enormous proactive force. For this reason the programs are selected from numerous mission proposals.

It must also be considered that the selection of a mission, or the type of missions, can have a technological impact, in other terms a return, on the industry which develops the program in question. Scientific mission can sometimes serve as a testing ground for future applications. Technological risks are often taken because of the specificities of the missions which require very high performance for their success.

For example, let's consider the technological returns for an industry which through a scientific mission plans and develops a communication antenna for an interplanetary probe whose link-up specifications involves distant celestial bodies millions of kilometers away; such high project requirements make this product a technological test of enormous impact on all future antennas produced. The technologies developed can give the industry knowledge and a commercial "competitive edge" to use in the future.

For the purpose of the subject of this book, we will refer to scientific missions realized in the framework of the ESA's Science Directorate activities, and which are a reference of the activities in Europe for this sector. What is more, scientific activities were the basis for the creation of ESA itself and are the object of annual obligatory funding by ESA Member States in proportion to national gross domestic product. Obviously this process has been fully derived from the NASA science program selection process when during the 1970s ESA engineers were heavily cooperating with their US counterparts to understand how to deal with the space science.

The selection steps for an ESA scientific mission occur according to cycles which occur regularly according to the chart in Figure 2.6 and can be generally summarized in the following phases:

FROM 2 TO 3 YEARS

PROGRAM SELECTION PHASES	ACTORS	NUMBER OF PROPOSED PROJECTS
CALL FOR IDEAS	Scientific Community	>>10
FIRST EVALUATION	Working Groups Space Science Advisory Committee	~10
FEASIBILITY EVALUATION	Scientific Community ESA Industry	
SELECTION	Science Program Committee	3 to 5
PHASE "A" DESIGN	Industry	
PROGRAM SELECTION	Science Program Committee	1

Figure 2.6. General decision-making model of an ESA scientific program.

- Proposal of various missions by the European scientific community, after a Call for Ideas by ESA (a Call for Ideas is an official request for new ideas and projects).
- Preliminary selection by ESA, according to special Working Groups and S.S.A.C., the "Space Science Advisory Committee," of a certain number of missions.
- In-depth examination of the validity of the selected missions by the Scientific Department of ESA's ESTEC technological center with the European scientific community.
- Intermediate selection by the ESA S.P.C., "Science Programme Committee" made up of representatives of the Member States of national space agencies, of few missions (from 3 to 5). This phase involves the endorsement of the S.S.A.C.
- Preliminary analysis (Phase A) from 1 to 2 years, led by various industrial groups to verify and propose industrial feasibility, costs, and time for delivery.

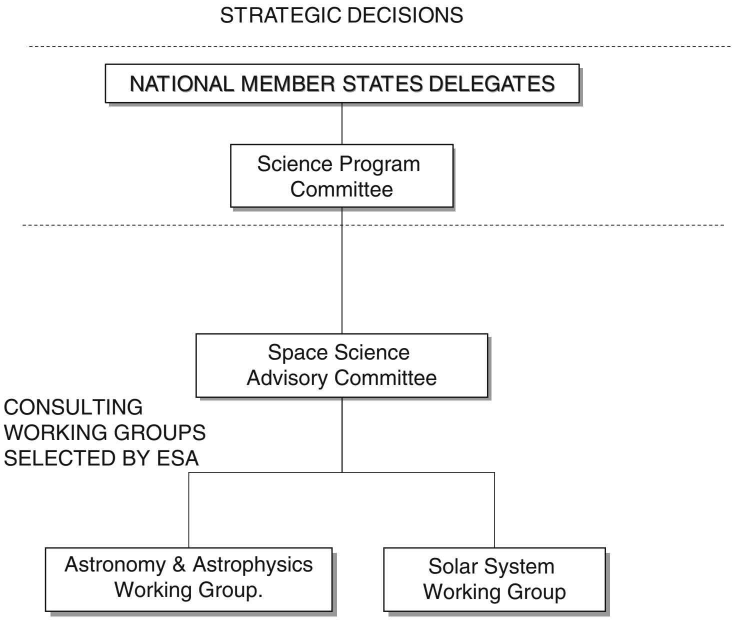


Figure 2.7. Breakdown of decision-making roles for an ESA obligatory scientific program.

- Final selection by the S.P.C. of a mission and start-up of the program with a formal tender to select an industrial group, the Prime Contractor, for the program development and implementation.

Therefore, in the beginning scientific missions in ESA, including large-size ones, remain within the framework of the S.P.C.'s decision-making competence and do not refer to the ESA Council level such as in the case of application programs. But in the last few years even the highest decision-making body of ESA has been involved in programs such as ExoMars for the exploration of Mars program. This is a result of increasing variances between the specifications of the mission (issued by the S.P.C.), the estimates for the development of the industry and the real budget possibilities of ESA.

In Figure 2.7 the roles of various Working Groups are clarified better and their breakdown, for the obligatory scientific program (astronomy and solar system).

Application Missions

The space applications usually include telecommunications, Earth observation and weather forecasting, navigation and satellite localization. In each case they can be divided into two main categories.

Operational Missions

These are space missions where the use of related technologies has reached a level of maturity that can now be integrated with user means, both professional and private. For example, there are weather forecasting applications which are used by government

users, public services or administrations for local, national or international forecasts; DTH "Direct-To-Home" television broadcast services which are used by millions of private users in Europe and in the world through pay subscriptions with service providers.

The requirements these applications fulfill are generally well regarded by users who sometimes, in the case of government users, can be the basis for the origin of the space program acting as decision makers and main or sole investors.

In the case of satellite television broadcast in Europe, for example, the start-up of satellite programs related to two service providers, Eutelsat and SES-Astra, illustrate this situation well.

Eutelsat was established in the 1980s as a European government organization, as the major national telecommunication companies, which were publicly held at the time, subscribed to them. It benefitted for its start-up of the service of the technological developments realized by ESA, through the satellites manufactured by European industry for ESA and a broadcast monopoly on various European territories. This was obviously due to the needs for the Member States who invested in ESA to ensure a return on investment. Then with time, the organization developed into a private business with private and nongovernmental shareholders and today it has been solidly established on the commercial market.

SES-Astra, on the other hand, clearly began as a commercial venture and therefore based itself on private initiative, which in the 1990s decided it was a potential advantage to invest in the DTH application in Europe.

European weather forecasting also followed a similar approach to the one followed in telecommunications and created Eumetsat, a European government organization which includes national weather forecasting services as shareholders and began to use specific satellites built by ESA.

However, in the case of ESA's operational application missions, the decision-making mechanisms are not the usual ones of business initiatives, where return on investment is the priority for starting up a program, but tend to introduce technological innovations that can bring about developments which lead space systems towards the highest possible TRL and ILR levels and therefore can attract the future interest of business firms.

Figure 2.8 illustrates a type of decision-making model for a mission of this type and refers to a generic Earth observation mission adopted by ESA within the framework of the Global Monitoring Environment & Security-GMES program.

Pre-Operational Missions

A pre-operational mission has different features since the evaluation of innovation component and the experimental component are significantly high, but at such a level as to allow the start-up of operations to validate subsequent operational missions.

The general model for a mission of this type is illustrated in Figure 2.9 for a generic example of pre-operation experimentation in orbit of an Earth observation satellite.

It is important to observe the emphasis which should be put on thematic analyses, the studies that define the mission and for this reason the type of onboard instruments to be developed to respond to the mission requirements.

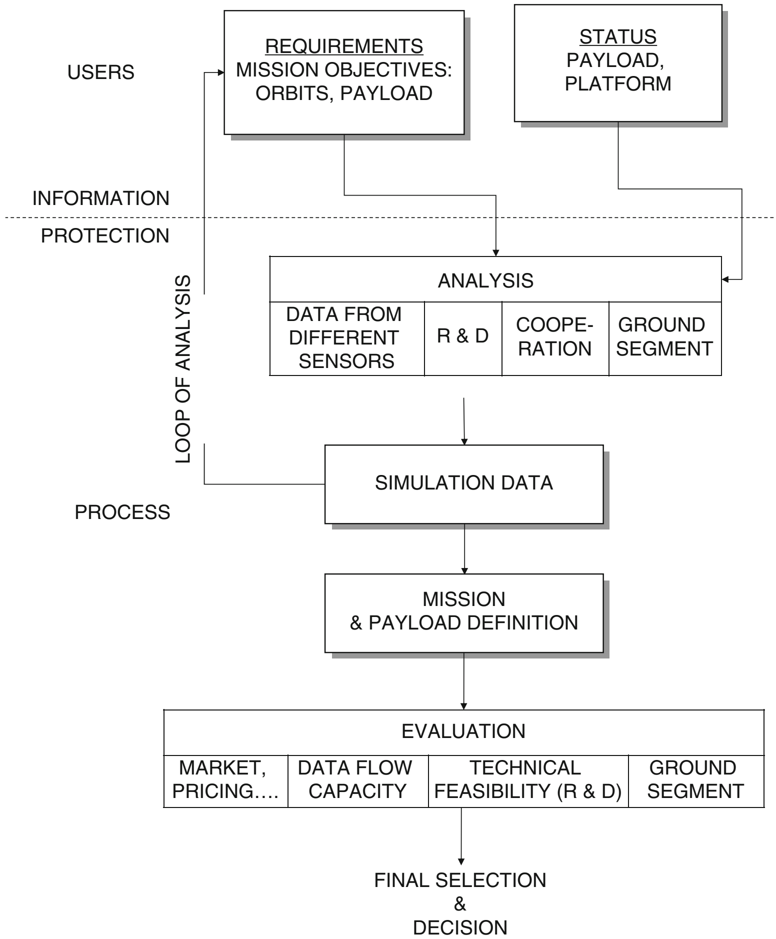


Figure 2.8. General decision-making model for an operational application program of ESA for Earth observation in the GMES (Global Monitoring Environment and Security) program.

Beginning with a requirement, or a series of requirements, such as the need to control the dynamics of vegetation or the surface of oceans for example, the thematic analyses must respond to questions of this type:

- Which parameters should be measured and how precisely?
- How often should the measures be repeated?
- Which sensor must be used to offer the best solution?

To give appropriate answers it is often necessary to use onboard or air-transported instruments to carry out effective measurements, experiments, and research for experimenting measurement campaigns and prepare future users to the use of operational data.

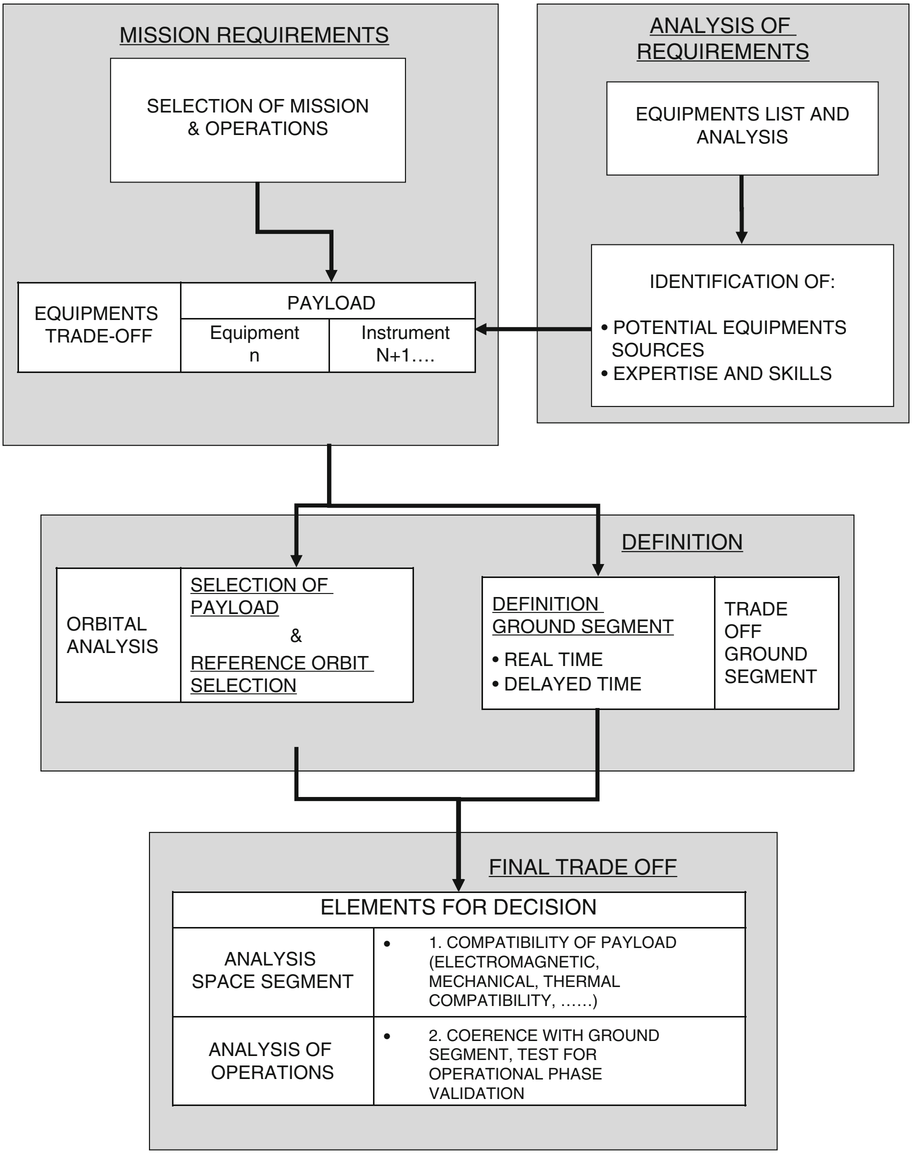


Figure 2.9. General decision-making model of an application-experimental ESA program.

The results of these preoperational campaigns must then be used to re-direct and improve the objectives of the mission.

In Figure 2.9 the definition process of an application-experimental mission is charted. A consultation has already been done which identified with some instruments suitable for fulfilling mission requirements.

As stated previously, in starting up this type of mission, it is not certain that the TLR levels of certain sensors or instruments are adequate, but it is for these reasons that the agency implements a program with those instruments to create technological and industrial innovation.

Commercial Programs

In the two preceding paragraphs the logics of development of the two types of ESA programs has been discussed. In 1975 ESA was the European agency to have created the foundation for the scientific and industrial programming of space projects. The process which brought ESA to adopt the logics of start-up and management of programs was highly influenced by its interactions with NASA. European experts, during the 1970s and 1980s, worked with their US counterparts to understand the problems concerning the development of space programs and to draw up procedures which were then "assimilated" to the US procedures already in place in those years.

The 1960s had brought well-known space successes to the USA. In the 1980s and 1990s following increasing commercial development, mainly in telecommunications, of satellite systems, the implementation of a commercial program developed decision-making processes which differ substantially from ESA or NASA's government agency logic.

Typically a commercial program has two basic features:

- The need for low-risk technology and low operational difficulty (developmentally and for use in orbit)
- The need for the highest economic efficiency of its system

These guiding parameters are the bases for technological and program choices. This is why a commercial system always involves the development of an already proven system with operational experience, high reliability and long operational life, with low development time and rapid injection into orbit.

As a result, the components are already qualified and tested in orbit and the development of the system does not vary from industrial processes already in place.

It is very rare for a business which intends to use space systems, for example, operators of telecommunication satellites or satellite images, to introduce technological innovations in their systems which would bear risks in the development and launch of the system.

Moreover, very often a commercial operator of satellite systems does not have the staff with specific space technology competences and uses outside consultants (experts in the space sector) who work to define the system and the subsequent control of the program.

The development of a commercial program therefore differs from the ones examined previously and generally consists of five phases, highlighted in Figure 2.10.

In phase 1 the company performs market studies, defines the business model to be implemented, evaluates the technological and economic risk, and essentially draws up its business plan.

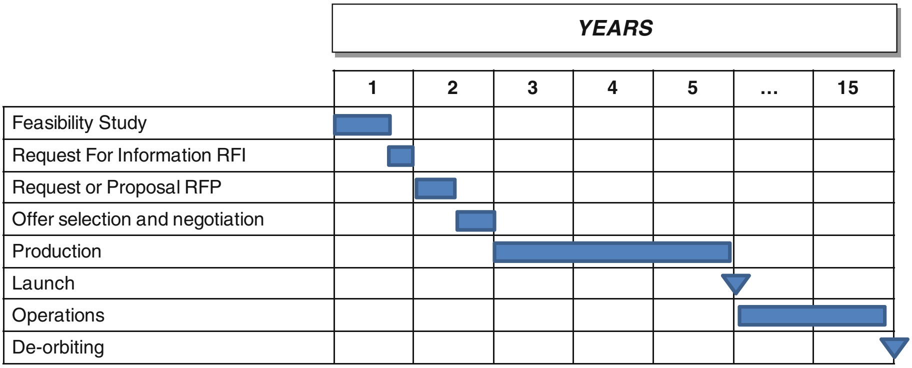


Figure 2.10. General decision-making process timing of a commercial program.

In phase 2 the company sends industrial producers it has selected an RFI, Request for Information, similar to the Call for Ideas mentioned previously concerning the start-up processes of ESA programs.

The RFI contains preliminary but fairly specific requests such as:

- Production experience
- Possible technical proposals to improve the effectiveness of the proposed production cycle
- Preliminary estimate of costs and timetable

In phase 3 the company sends selected industries, which have responded to the RFI, an RFP, a Request For Proposal. At this point the industry which wishes to win the contract to develop the program gives a detailed proposal of the program whose structure will be discussed in Chap. 3 and which does not substantially differ from the one put into place by the industry toward an agency such as ESA or NASA.

In phase 4 the company has selected the supplier, has signed the contract and the production process for the "procurement" of the system begins. The management of the program is the core of phase 4 and ends with the system going into orbit.

In phase 5 the supplier transfers the system in orbit to the customer (the company or agency which authorized the project) and commercial operations begin which last an undetermined number of years generally ending with a deactivation phase, in the case of geostationary telecommunication satellites this phase implies a de-orbitation of the spacecraft. The satellite is essentially moved, with a small amount of residual fuel, onto a slightly different orbit from the one used for operations so it does not "crowd" space.

2.5. Development Phases of a Space Program

Space programs in the world as in Europe were soon organized into *Phases*, corresponding to the development of the life of the program itself.

Once the feasibility studies have been done, the decision to start up a program or not is taken, and then the drawing up of the Management Plan is completed.

The program is finally realized, it is physically launched into space and the services/applications for which the mission was defined are used.

However, given the increasing complexity of space programs the minimum time between the first feasibility studies and launch into space can vary between 28 and 36 months needed for realizing, for example, a commercial telecommunication satellite, or from 6 or even 10 years needed to realize and qualify a launcher. In several cases, we have gone over 15 years, such as for the realization of the ISS.

This long-term time frame leads program managers to detail the timetable of the Management Plan into *Phases* which are finally defined as the development objectives to be followed. The organization of the various activities, objectives and intermediate results into a time framework is indispensable today.

Every passage from one phase to another is authorized by program managers and contractually confirms the technical consistency of the work performed up to that point by the industrial group. In so doing the question of technical choices of the preceding Phase is avoided, unless there are major problems in development.

Logic of Program Control

Because of their size and technological specifications, space programs take many years to achieve with an investment budget of hundreds (and even thousands) millions of euro.

Building in 30 months a large commercial telecommunications satellite with over 50 transponders on board can cost over 300 million euro, including the manufacturing of the satellite, the purchase of the launcher, the insurance and the construction of the ground segment.

For example, the construction and launch of the first four Italian satellites of Earth observation, Cosmo Skymed, cost over 1.2 billion euro in 5 years.

Therefore, it is impossible to wait for the end of a program to verify whether it is satisfactory to the users.

It is necessary to control the program activities to validate technical and economical solutions adopted as the activities develop during the course of the program.

The biggest problem for controlling these activities involves:

- Decisions which influence investment too early in the program (see Figure 2.11)
- Nondeviance from initial requirements

The logic of control can be defined correct if:

- Ensured convergence toward the specified development objective step by step, with cost and time conditions are duly respected.
- Management of a progressive and controlled commitment of the means and resources for developing the program, with choices that should not hinder technical solutions prematurely.
- Consolidated results through the program are achieved to reach the progressive development of the system step by step.
- We provide for a time and financial “reserve” from the beginning called “contingency” or “margin,” as illustrated in Figure 2.12.

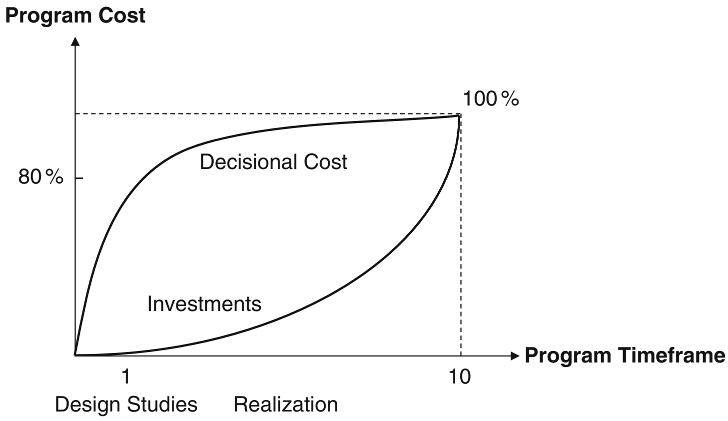


Figure 2.11. General cost/length relation of a program.

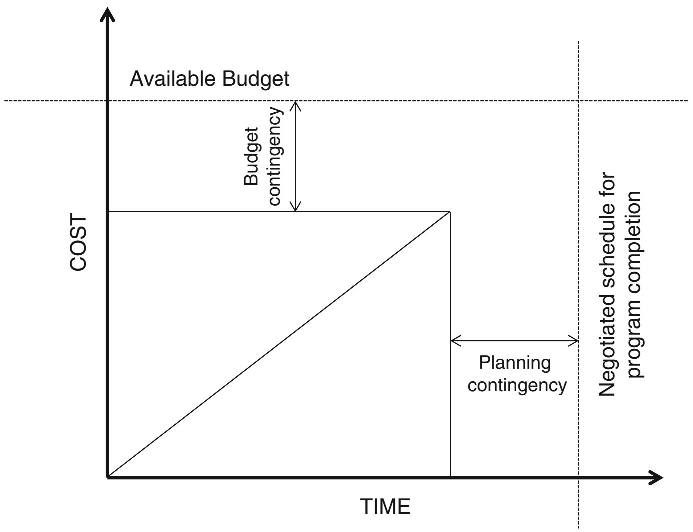


Figure 2.12. Definition of the "contingency" for budget and time management.

This logic leads to subsequent steps approach and key events, called "milestones" which cover various Phases throughout the duration of the program. Each Phase is characterized by a milestone.

Every milestone allows us to:

- Verify what has been developed
- Verify what influences negatively the progress of the program

Milestones are the opportunity for analyzing:

1. Production quality
2. Potential delays or already created ones
3. Actual and future costs
4. Means used and to be used
5. Resources used and to be used

A milestone includes two events:

1. A validation which can be performed by external and internal authorities to the program who give their recommendations on the Phase, in progress or terminated
2. A decision by the program manager on the progress of the activity including the application of issued recommendations

Since the 1960s the USA has felt the need to standardize project logics and this process was established with the drawing up of a series of requirements called the NASA Military Standard. Through these standards the customer and contractor possessed the specific program procedures to be followed.

Beginning in the 1970s, after the inception of ESA in 1975, a similar need was felt in Europe. The ECSS, European Cooperation for Space Standardization, standard was developed and internationally recognized and assimilated to the US Military Standards.

The ECSS are subdivided into three levels:

1. Series E, engineering
2. Series Q, product quality
3. Series M, management

And have three different levels of detail. In the first there are the standards for determining strategies and requirements, in the second management functions and objectives and in the third level the guidelines for reaching level 2 are outlined.

Figure 2.13 shows an overview of ESA's ECSS.

Let's go on to define the various program Phases. Each Phase ends with a "review," a large meeting in which a committee ("board"), with specific program managers and experts, analyzes the results achieved and on this basis defines action for control and recovery, and deciding whether to proceed or not to the next Phase.

Phase 0, or Mission/Project Concept

After a Call for Ideas generally various projects for missions are examined and the managing authorities of the program select only few of them for a more in-depth analysis, the Phase 0.

The objective of a Phase 0 is to gather the elements which allow to judge formally the size of a program, level of industrial, technical and financial requirements deemed necessary for the mission's requirements.

Consequently, in Phase 0:

- The mission must be defined and its objectives clarified.
- One or more systems that can achieve the mission must be identified as well as the major problems to be resolved.
- An estimate of the means, timetable, and resources necessary must be drawn up.

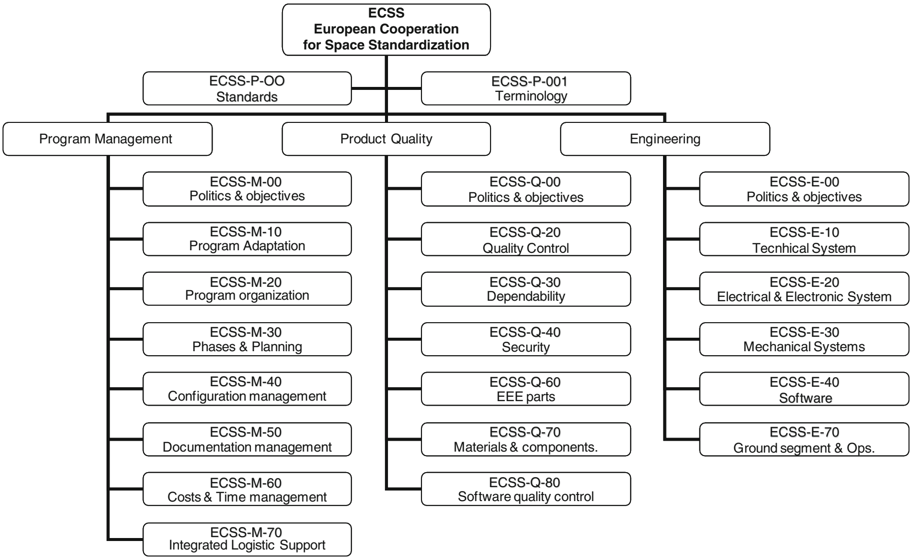


Figure 2.13. Overview of ECSS, European Cooperation for Space Standardization.

Phase 0 is executed with a preliminary project which must allow decision-making authorities or the customer to follow or not follow through with the analysis of the mission under consideration.

A positive decision at this point is a key moment for the program, it is a decisive step and really begins the program.

The final review of the Phase 0 is called MDR, "Mission Definition Review."

Phase A, or Feasibility Study

Usually, following Phase 0 if the proposal has drawn enough interest for its development, Phase A is begun for a more in-depth analysis.

Therefore, the objective of Phase A is to evaluate the program's feasibility under technical aspects, cost and time, leading to a more concrete identification of risks associated with the development of this program.

Therefore, during Phase A:

- The objectives of the proposed program are clearly stated and the mission requirements duly identified.
- The financial and strategic analyses are also detailed.
- Technical modalities for realization and implementation are analyzed to synthesize the main technical difficulties to be overcome and to estimate the possibility of concretely achieve the objectives of the program.

At the end of Phase A a technical-financial report must be drawn up as well as an analysis relative to the program's implementation which must contain:

- A development plan proposal, "Development Plan," with the technological R&D plan that will be necessary for developing the program (for example, for the European program Galileo for satellite navigation, the Development Plan also

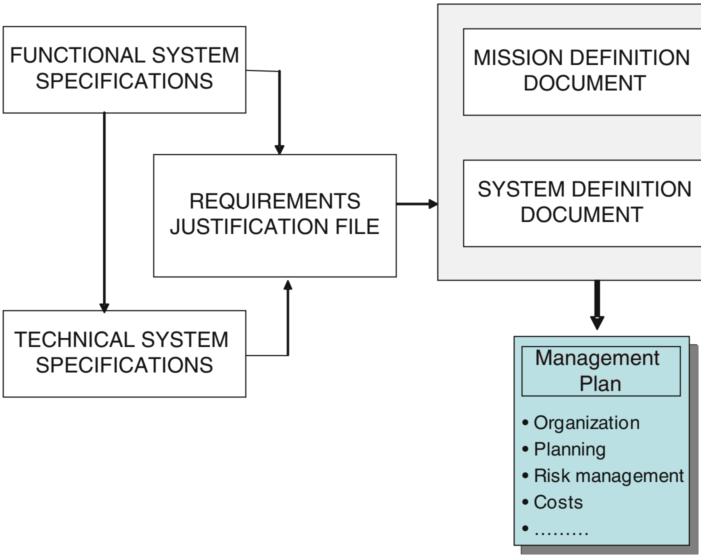


Figure 2.14. Document planning of Phase A.

foresaw an R&D plan relative to the development of onboard atomic clocks whose technology was present in Europe but not developed for space flight).

- A proper and realistic evaluation of costs and time for realizing the program, identifying margins of uncertainty. For example, in the development of a commercial satellite, an incorrect estimate of delivery time causes the customer, i.e., a commercial operator, a loss of return for selling lately the service, and for the industrial group a payment penalty by the customer.
- A realistic project of the financial model of the program, its management organization and related documentation.

Figure 2.14 illustrates the flow of relative documents of various activities which will then be the basis of the final "milestone" of the Phase, the final review. This flow is extremely important for following the program because basic requirements for starting up the program develop from it.

Usually in space programs, at the time Phase A is completed, an initial large meeting is held to review the analyses performed, the PRR "Preliminary Requirements Review."

The decision-making authorities, for example, the customer, whether ESA or another purchasing agency or commercial operator which is ordering a product, participate in this meeting. Then there is obviously the participation of the industrial group which has done the analysis and there might also be present agencies and external resources to the program with a declared expertise that are called upon by the decision-making authority to help evaluate the report.

The results of the review lead to the selection or nonselection of the program, considering the recommendations for modifications and/or variations issued by the members of the review board during their analyses.

Efforts in terms of resources to be used in Phase A obviously depend on the breadth of the program to be implemented. For example, the Phase 0 study of a new launcher can last several months and up to over a year, using dozens of resources, i.e., months of manpower.

Phase B, or Preliminary Definition

The objective of this Phase is to reach a complete definition of the program. The start-up of Phase B is already an important choice by decision-making authorities since it validates the technical-financial choices made in Phase A and therefore adopts the technical options which form the basis of the program.

The start-up of this Phase generally indicates the taking into charge of the program by its developers and because of its importance a significant amount of work is performed, especially:

- The analysis and definitive choice of the system/product to develop in the program. For this reason there is an evaluation and discussion of concrete technical choices. Once they are completed they will make up the specifications of the system to be developed.
- The definition of the system architecture and of the functional distribution of the various subsystems.
- The definition of the future program with regard to Research and Development.
- The writing of the complete Development Plan, of the number of platform to develop, testing and qualifying procedures and means for these purposes (for example, the detailed definition of mechanical and electrical instruments for testing).
- The definition of the managerial and industrial organization charged with implementing the program, including a detailed evaluation of the means, human and material, which are needed.

The end of Phase B is also subject to a program review, generally referred to as PDR, "Preliminary Design Review."

Frequently, due to the size of the program the financial investment can be heavy also to complete Phases A and B, therefore this phase is subdivided into two or more sub-Phases, called B1, B2….Bn. Each of these phases ends with an intermediate review, referred to as SRR, "System Requirements Review," whose implementation and conclusion are necessary for the start-up of the subsequent sub-Phase.

Generally speaking, B1 is aimed at defining the system's specifications and B2 to subsystem specifications. However, each program may be subdivided into sub-Phases according to different criteria. This method helps a leveraged up-front investment.

In Phase B the program usually mobilizes already enormous amounts of resources and of capital, and the effort made in terms of months/manpower can turn into a complex satellite project (for example, ESA's scientific satellites) with dozens more months/manpower. Even the cost of Phase B reaches 10–15% of the total cost estimate of the program. Therefore, the conceptual choices of this Phase determine 80 or 90% of the program's implementation cost.

Thus, the importance of the decision to continue the program at the end of the PDR of Phase B is evident, since the subsequent Phases will concern the actual implementation of the program.

Phase C, or Detailed Definition

The objective of this Phase is to achieve the implementation specifications.

In this Phase the industrial group is called upon to detail the constitutive parts of the program and the conditions for their realization. Therefore, it is a major industrial operation which involves not only detailed studies, but also models and preliminary testing.

The CDR, "Critical Design Review" comes at the end of Phase C and precedes the realization phase.

Phase D, or Production

During the course of this Phase of the program, the system is built and tested, and its ability to fulfill the mission's requirements for which it was implemented is verified.

Obviously this verification occurs under operational conditions and on a structure which will be used on the mission.

A specific review of operational qualification ends this Phase. Usually, given the complexity and time length of Phase D, various intermediate reviews are necessary and their importance is heavily affected by the launch time deadline.

In programs for developing satellites and launchers, for example, Phase D is broken up into steps with specific reviews, for example, the QR, "Qualification Review," the PCR, "Production Configuration Review" up to the AR, the "Acceptance Review," which take stock of the situation and which are mandatory passages (milestones) which must be passed for the progress of activities which in fact end with the launch of the system into space.

The decision taken by decision-making authorities to go to the next Phase, following a positive "Acceptance Review," concludes the end of the program's development.

Sometimes Phases C and D are "unified" under the term Phase C/D.

Phase E, or Operations

The space system developed by the program is launched into space during this Phase and operates by supplying services for which it was designed.

The ORR, "Operational Readiness Review" provides evidence of the system's function and authorizes the start-up of the launch campaign which ends with the FRR, "Flight Readiness Review" which gives the definitive and final approval for launch into orbit.

Usually, for a telecommunications satellite, the ORR takes place 2–3 months before the launch and starts up the launch campaign, the sending of the satellite to the launch site for final test operations, loading of fuel and final integration with the launcher. The FRR takes place the day before the launch and after its positive conclusion the launcher is loaded with fuel and sent to the launch sequence.

Once in orbit, a scientific satellite's instruments begin to operate and transmit the data for several years, a telecommunications satellite begins to receive and transmit radiofrequency signals on the geographical area it covers for over 10 years. A launcher instead puts into orbit and releases a satellite it is carrying on board after less than hour from the launch time to Earth, and so it ends almost immediately its operational Phase.

It should be noted that in the case of recurrent production systems, mainly referred to commercial satellites or launchers of the same version, the functional data gathered

during the course of Phase D often lead to significant modifications of the system during its lifetime.

Here is where the program introduces modifications at every level in its Development Plan and this leads to a new process in Phases, obviously noticeably accelerated compared to the initial one, which observe the logic foreseen, however modifying elements or subsystems of the original development process.

This analysis can lead to Phase F, or final placement, with the conclusion of the operational life of the system and its deactivation.

A synthesis of the Phase process is summarized in Figure 2.15. In this planning there is a variable "time" frame axis inserted, i.e., the measure of the duration of the project as a nominal duration of the program.

The project flow which is defined above does not only apply to the program's Prime Contractor, but in cascade fashion involves all the sub-suppliers for which the review process is managed directly by the Prime Contractor. However, the approval for the advancement and payment is usually delegated to the main customer. This is the common practice for ESA programs.

Obviously, at the level of equipment and subsystems, the project flow must come before the system and critical reviews must be done before the program Phases, otherwise the impact on overall planning would become unmanageable.

Figure 2.16 illustrates a functional hierarchy of the project's responsibility as an example of this.

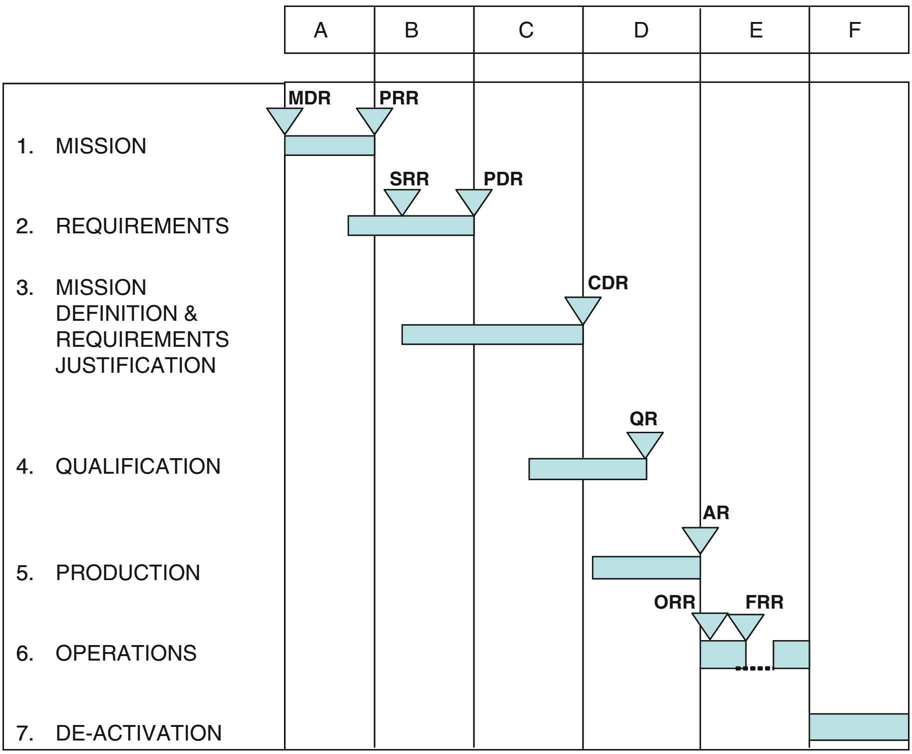


Figure 2.15. General model of the program Phases.

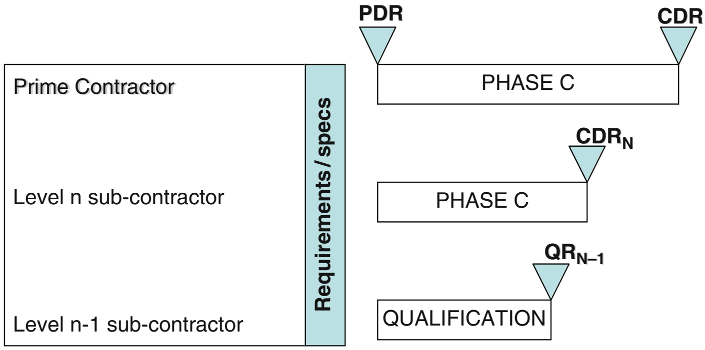


Figure 2.16. Example of the hierarchy of program responsibility.

There is a difference between the methods used for institutional programs, such as ESA's and the practice for commercial programs for which technological innovation, with greater risk, are usually neglected.

However, even in commercial programs the ECSS standardization model is used as a model, because the quality control and production flow represents in any case a guarantee of product reliability for the customer.

Advantages and Limitations of Subdividing the Program into Phases

The organization of a program into progressive steps forward and intermediate decision-making steps have an undeniable advantage in terms of:

- Criteria and progressive definition of the activities to be developed and the necessary means.
- Engaging means and necessary resources only at the right moment.
- Control by responsible authorities of the state of advancement and possibility of implementing more effective management techniques.

On the other hand, limitations are present essentially in the difficulty of describing in stable and standardized models the complete process of development of a space program which develops in a government, industrial, and commercial context in constant evolution.

The creation of Joint Ventures or industrial mergers, intergovernmental or commercial agreements are variables which can influence the life of a space program which lasts many years.

Obviously, the program managers must organize activities with thoroughness and logic to predispose a solid and orderly organization of the Management Plan as much as possible. However, they have to include flexibility in the organization to adapt to potential evolutions of the context.

Quite often, this requires imagination, common sense, and notably human and organizational flexibility, which can seem contradictory with the notion of engineering organization for rules and procedures.

In doing so, managers can therefore be free to design the name and type of the organization in Phases within the Management Plan in broad terms. Next to the letters 0, A, B, C, D, E each manager can, according to the program and the circumstances under which it is developing, add contents to the Phase according to logic and specific development consistency.

For example, it should be noted that in a space program various aspects converge, in making an organization complex by distinctly dividing it into Phases.

Technically speaking, it is often necessary to override Phases because of development reasons. A Phase C/D can begin with several subsystems during Phase B of the program due to supplies or the beginning of long-term work (realization of building a launch base for example). In another case, several technological developments which should usually end in Phase B can continue on during Phase C/D.

The way different parts of a program advance are almost always different. For example, for a commercial satellite program the definition of Phase B for the ground segment development (reception terminals, for example) must wait for a detailed configuration of the space segment (for example, onboard payloads), which cannot take place during Phase C/D.

Finally, the same decision-making process does not always express itself in a synchronistic manner in time with the program's development since during the course of its development this requires a significant amount of intermediate operational decisions which overall will make up those technical choices to be evaluated in terms of each Phase in the appropriate review.

It is the task of the Program Manager to harmonize all these activities by coordinating them in time.

The Program Reviews

The program reviews are meetings of limited duration (from 1 day to several weeks) held at pre-established times in the Management Plan and during which the program activities are presented, examined, and criticized.

The program review is a shared tool for controlling and managing the program for decision makers and the Program Managers.

The objective of the program review is to:

- Consider program activities at different time steps.
- Support decision makers and Program Managers in controlling the state of advancement of activities.
- Give decision makers and the Program Manager tools for evaluating if the activities allow the continuation of the program or its realignment.

For this purpose, the method applied to this review is the following:

- Take appropriate distance from usual activities (meeting place, type of behavior) to examine the elements of the program.
- Support different positions without the restriction of discussions and debates.
- Call upon technical and managerial experts outside the program who can introduce new elements into the program, highlighting anomalies or improvements.

Every review is usually organized so that a “review group” made up of a certain number of people not necessarily directly involved in the program evaluate it by examining documents and attending presentations by the Program Managers and industrial group.

The review group, which elects its President, issues “observations” and “recommendations” written on standard forms which are sent to decision makers and the Program Managers for appropriate evaluation and actions.

An essential aspect is the organization of the review and it is useful to distinguish that there are two important periods in the life of a program for which reviews should be set up at different levels (system, subsystem, and equipment) in different manner.

The first period is the definition of the program when activities involve study and concept-making, and the subsequent reviews can “diverge” to various levels (system, subsystem, equipment), but are conducted chronologically in increasing order.

The corresponding Phases are 0, A, and B.

The second period is the program development when the activities involve building and testing, and the subsequent reviews “converge” at all levels towards the reviews of the system.

The corresponding Phases are C and D.

The reviews can have various forms according to the program function and organization of the review group. However, given the nature of space programs, these meetings always maintain a certain formality of procedure that is appropriate to the limitations of diffusion and confidentiality which shared technical information often requires.

In review groups, one must always keep in mind that the objective is not to take the place of the Program Mangers, but to get the best possible evaluation of how the program is progressing.

Through specific numbered technical notes, issued by the industrial group, the review group takes notes of the problems which have been brought up for subsequent discussion and possible shelving. Should a problem not be shelved it gives way to an action for the authorities to verify and subsequent closure of the problem.

The review group, guided by its President, steers the meeting, establishes the agenda, gathers technical notes of the problems to be resolved, organizes analyses for necessary solutions, and synthesizes the activities performed.

His role is essential for presenting to the decision makers observations and final recommendations during the concluding meeting of the review.

It is not an easy task to gather competent, motivated and available people for a review group.

Decision makers and the Program Managers have to show common sense and sharp skills for choosing and assembling the right people, many of whom are not directly involved in the program, who can truly understand the technical choices made and understand possible development problems.

This is the actual basis of the review: to ask competent questions and perceive possible problems.

Therefore, for a successful review one should have a well-prepared review group, the right mix of internal, external and people close to the program and definitely a major personal attachment to the activity.

The main risks of the Review are almost always due to excessive formalism where form is criticized and not the real issues involved. Another risk is superficial examination of the relevant aspects of the program in a limited time frame.

One of the main tasks of the President of the review group or its steering committee, the "board," is to minimize these risks.

Chapter 3

Marketing of Space Programs

3.1. Notion of Marketing

In terms of economics, marketing is required when supply is greater than demand. This occurs when products, or projects, offered by industries and companies are greater than the number of customers who can buy the products, or finance the projects.

In this sense, demand can be understood as an interest to purchase for commercial purposes (for example, a telecommunications satellite operator who intends to buy a satellite to increase its profits) or the ability to spend for various reasons (for example, the European Space Agency intends to award a large contract for making a scientific satellite to increase our knowledge of the universe).

Economists generally classify economic situations into four types:

- Production economy, when industries do not produce enough what customers require. In this case, there is no need for marketing.
- Distribution economy, when there is a balance between supply and demand, this is obviously an ideal situation and even in this case there is no need for marketing.
- Market economy, when the industrial supply is greater, sometimes much greater, than the demand. In this case the marketing is an essential tool.
- Context economy, when noneconomic but equally influential players (for example, governments, institutions and agencies) become involved, very often indirectly. This type of economy very much resembles a market economy in which marketing becomes even more important given the context in which it operates.

Space programs fall into the category of the last two types of economies because marketing plays a significant role in the sector which must adapt to the previously defined special features of space activities.

However, marketing, especially within an industry, must be in step with the market.

In other terms, management must have a commonly directed understanding of the market.

M. Spagnulo et al., *Space Program Management: Methods and Tools*,
Space Technology Library 28, DOI 10.1007/978-1-4614-3755-0_3,

This is not always the case in space programs because high-tech industries are often driven by engineering. Their primary objective is to improve technology, directing the program more towards innovation rather than the customer's real expectations.

Markets with strong government backing such as space programs very often present this feature.

The drive towards technological enhancement can therefore be counterproductive, but there is also a paradox in which the space industry tends towards a production economy, just like all industries, where it increases its own budget margins, business volume, and then profits. In so doing, the industry aims at technological innovation which once perceived and accepted by the market, drives the industry towards a production economy.

This is why the industrial mix for a space market fluctuates between innovation and its own limitation significantly. When the budget can ensure a good economic context, fluctuations are more easily absorbed by the industrial sector.

3.2. Function of Marketing in a Space Program

There is no single definition of marketing for space programs. We can define marketing by considering two different viewpoints. The first definition is based on the viewpoint of someone with no special technical training and the second by professionals in the sector. This is why we would probably find two facets which appear different at first glance.

For the layman, marketing probably consists mainly in advertising and other forms of promotion. This is due to the influence of businesses on people to buy or consume products and would therefore be an instrument for exerting influence.

For the marketing professional, however, marketing is the process for knowing and foreseeing what the customer has in mind and to understand how the company can fulfill the customer's needs in an economically effective way in this situation. Marketing is therefore an analytical tool.

For space sector industries, which usually are located midway between a market and context economy, marketing corresponds to the sum total of both viewpoints. Depending on which of the two economies prevail, influence marketing can be more or less a priority compared to analytical marketing.

For example, for a space program in a context economy system such as the European navigation system Galileo, influence marketing is certainly a priority and essential, and forces marketing analysis into second place because of the political, strategical, and economic context of the program itself.

On the other hand, a commercial program for selling a telecommunications satellite to an operator, analytical marketing is a priority.

At the start of space activities, the context economy predominated. Since 1970s both economies, context and market, have developed significantly. However, since the 1980s marketing has gained more importance in production and has become at times a central function, certainly not more important than production, but it has an important role as "the customer's ambassador" for production, administrative, or financial functions. For example, the commercial function of the European company

Arianespace which has been selling launch services into space since 1980s for the Ariane launcher is a central and highly influential element in the industry's organization.

In examining the special nature of the function, we must also consider the fact that marketing does not correspond to the same functions in all industries or all countries.

In Europe the Marketing Director of a space industry generally involves all the analysis and influence functions, but not sales, while in the USA the Marketing Director includes influence and sales functions, while analysis is performed by a technical unit.

However, there is no basic rule even in these cases. The previously mentioned Arianespace was the first in Europe to develop an organizational model where a Commercial Directorate includes marketing analysis, influence, and sales.

Therefore, there are no preestablished solutions (Figure 3.1).

If there are separate functions, internal rivalry would probably result which could harm the industry since it would create obstacles. However, they can be beneficial to critical analysis and intellectual variety which astute management can profit from.

In conclusion, the American approach reduces the risk of conflict, but with the potential invasive development of marketing's power in a company life.

3.3. Marketing of Programs and Services

The space sector has been characterized at the beginning by a significant amount of innovation and the rather significant importance of technology.

When a space program involves more effective, innovative and ingenious technologies, the industry gains a competitive edge.

Marketing mix is therefore the result of the mix of economies—market and context, in which the program is set forth.

The marketing mix of space programs cannot be generally classified as consumer market, i.e., "business to consumer," but as a "business to business." It is the sale from business to business or organization enacted through a specific marketing program.

The marketing of space programs characterizes businesses which propose unique complex projects even when they are repetitive; for example, the production of launchers in series.

The marketing of space programs therefore requires adapting one's own development philosophy because realizing a space mission requires sophisticated savoir-faire and an enormous economic and financial investment.

For example, the procedures for tenders or Call for Ideas of space agencies have been defined for years and are constantly applied with standard methods that also influence the procedures for commercial tenders.

In each case then marketing strategy basically involves creating a close network of relations before the tender, or request of offer to be able to influence the customer in some way concerning the definition of the program requirements.

The marketing of space programs, which is much more sophisticated compared to classic industrial marketing or with consumer goods marketing, still offers the

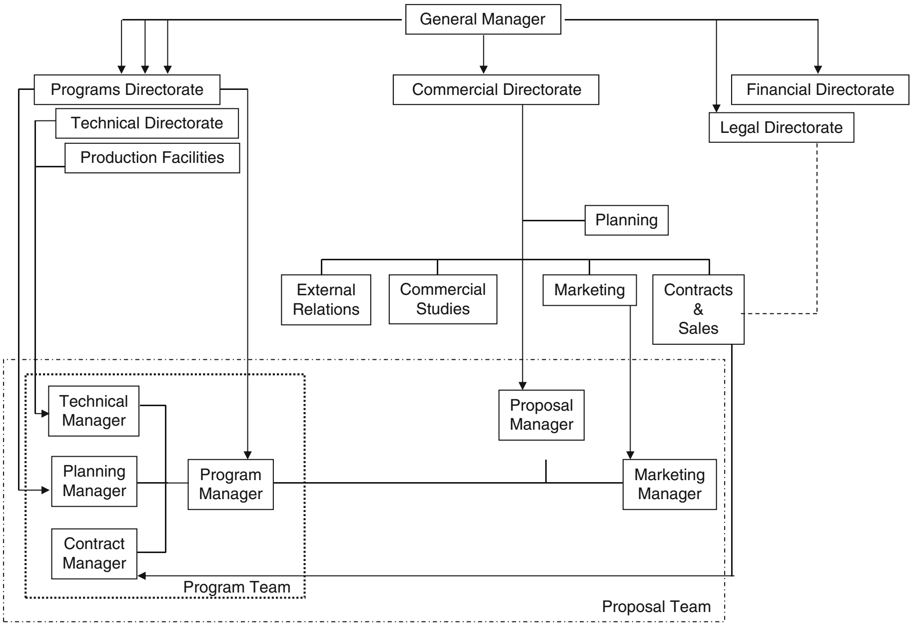


Figure 3.1. An example of industrial and marketing organization.

potential for development despite certain procedures which have been established, as previously stated.

For example, in the mid-2000s the marketing of Skynet V for the development and putting into orbit of satellites for military telecommunications for the British Defense Ministry, was an innovative model for space programs since it was the first time a type of Project Financing for military-type services was used.

The marketing of space programs features "business-to-business" transactions between suppliers of devices and equipment, subsystems manufacturers, system integrators, and lastly customers.

The chart in Figure 3.2 illustrates the business chain.

In essence, only the final transaction can involve the consumer market, the marketing of services; for example, telecommunications via satellite of the DTH business "Direct-To-Home" television generated by the final applications aimed at consumer sales through subscriptions to television channel packages.

Satellite navigation business is of particular relevance.

In this case the consumer market has been developed through the development of application systems (navigators for cars or mobile phones, for example) which use the radio-electric signal of GPS satellites without charge even though these satellites were not developed for commercial purposes and which are either the property or under the control of operators who sell broad-based consumer applications related to them.

In other words, in buying a satellite navigator for cars there is no commercial guarantee on whether it will continue to work because the owner of the GPS system, whose signals are used and which are therefore part of the commercial transaction

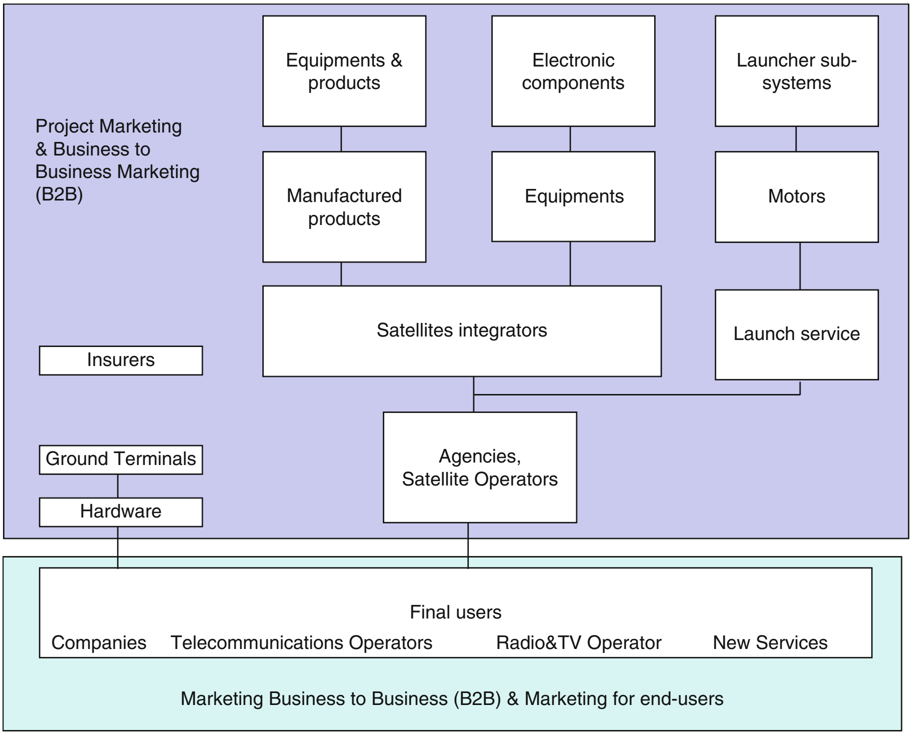


Figure 3.2. Business network for space sector marketing chart (example of commercial or government telecommunications system).

between the buyer and the seller of the navigator, is the US Defense Department which can alter or interrupt the signal according to its own national security requirements.

On the other hand, in the case of a commercial subscription to Pay-TV in which a final user who buys the subscription, the service provider supplies the reception device and the operator, who is almost always the owner of satellites, there is a financial transaction which regulates the modalities and service commitments.

3.4. Offer in the Marketing of a Space Program

The steps involved in offer and subsequent contract negotiations make up the two final and essential elements of program management which also includes sales.

Here is where the word marketing in space programs can be identified with the process of offer, negotiation, and signing of the development contract.

In commercial type programs, the proposer, the system supplier, responds to a request of offer sent by the customer who intends to buy a determined product under the best market conditions. In this case marketing is essential for the proposer to be on the list of those to whom the offer is sent.

In institutional or government-type programs where the customer is a space agency, the tender is published through specific instruments (notices, Web sites) and the proposer must have been previously authorized to accept these information instruments with proper registration and accreditation.

In both cases the customer prepares a document called a SoW, "Statement of Work" in which the specifications and the type of work requested are provided in as much detail as possible.

The SoW is the foundation document which allows:

- The customer to request precisely to the selected suppliers, or in any case, the various proposers, precise and detailed response to go on to proceed to the final decision.
- The proposers to define their technical and financial offer in the best way possible.

Generally in the development program of a commercial telecommunication satellite, the SoW is generally made up of documents such as:

Volume 1: presentation of the mission, system and conditions of the tender.
Volume 2: elements which make up the supply.
Volume 3: technical specifications.
Volume 4: management, quality, develop and testing specifications.
Volume 5: the guide for the offer and evaluation parameters.

Therefore, the proposer must provide the requirements defined in the SoW in his offer, paying careful attention to the overall compatibility of the offer with those of the evaluation parameters indicated in the SoW.

Therefore, the definition of a compatibility matrix must be defined in the offer which will provide the customer with a schematic visualization that the offer adheres to his requirements.

This compatibility matrix is essential for all tenders whether they are commercial or government since an offer of a system which exceeds the performances defined in the SoW can be rejected because of excessive costs or technical efficiency or uncertainties regarding technical risk.

The offer must also be made up of various elements such as:

- The letter of offer which is essentially a business letter in which the managers of the proposing business express the technical and financial details of the offer in synthesis.
- Volume 1: an "Executive Summary," made up of a brief dossier with relatively few pages containing all the features of the offer.
- Volume 2: the technical offer, i.e., the descriptive details of the development proposed and the processing for testing and qualification.
- Volume 3: the management and administrative offer which indicates the management configuration, i.e., how the proposer will organize the program in terms of resources, choice of subsuppliers, program review, and decision-making milestones.
- Volume 4: the financial offer, containing the proposed price, its details, the eventual revision and payment plan.

Volumes 2 and 3 make up the "Management Plan" defined in Chap. 2.

At this point we should focus on the four fundamental aspects of an offer on which the entire management of the project will be focused on: the development plan, the charting of single activities, timetable planning, and price (including costs).

The development plan is expressed through the drawing up of an organizational structure called the WBS, "Work Breakdown Structure" which "unwraps" each activity to be developed, called the WPs, "Work Packages" and identifies each of them according to a reference index. Each first-level WP will be broken down in turn to a series of secondary-level WPs and will go down to the basic level.

As an example, let's observe Figure 3.3 in which the WBS shown is the development plan, subdivided into basic activities, of a telecommunications satellite. As we can see, not only technical but also even administrative type activities such as contract management or suppliers must be reported and then quantified in terms of time and performance in the relative WP descriptions.

The WBS in Figure 3.3 has been purposely simplified in the number and detail of the WPs, but it is evident that the Program Manager will have to "build" his own development plan from the offer phase with a WBS which matches as much as possible all the basic activities which can be imagined which will make up the total program.

In fact, the WBSs of space systems are extremely complex "structural maps" which are however a crucial element for the Program Manager in support of development. This is why they are established during the offer phase and then become a mandatory reference during development phase.

In Figure 3.4 the basic WBS for a development plan for a space launcher is also provided as an example. In this case the "administrative" type activities have not been reported, and only operative activities are considered for didactic purpose.

In analyzing the charts relative to Work Packages, we see that they generally follow the structure illustrated in Figure 3.5.

In fact, the descriptive chart of each WP must include the key features of the activity it describes: the beginning and end of the activity, responsibility, objective of the activity, input elements for starting up the activity and results, configuration, and especially a description of the activity.

The descriptive quality of the project WBS and WPs is the keystone of quality for project planning. Its level of detail must not neglect elements which could be underestimated in a critical way during the development phase.

After a systematic structuring of the WBS and relative WPs, the third essential aspect is the explanation of the time management of the plan which is an integral part of the definition of the WPs in which the resulting sum of the "date of start-up" and "final date" express the overall duration of the program.

Figure 3.6 illustrates a time plan regarding a development project for a highly complex telecommunication satellite (the duration for the realization of a commercial satellite weighing 6–8 tons at takeoff and generally lasting 4–5 years).

The three elements described above quantify the material and human resources required for realizing the program. This process is extremely important since it allows the Program Manager to pick out the so-called "critical path," which is the mix of human resources and timetable of basic activities which must be absolutely achieved to limit delays and/or cost overruns to the maximum level.

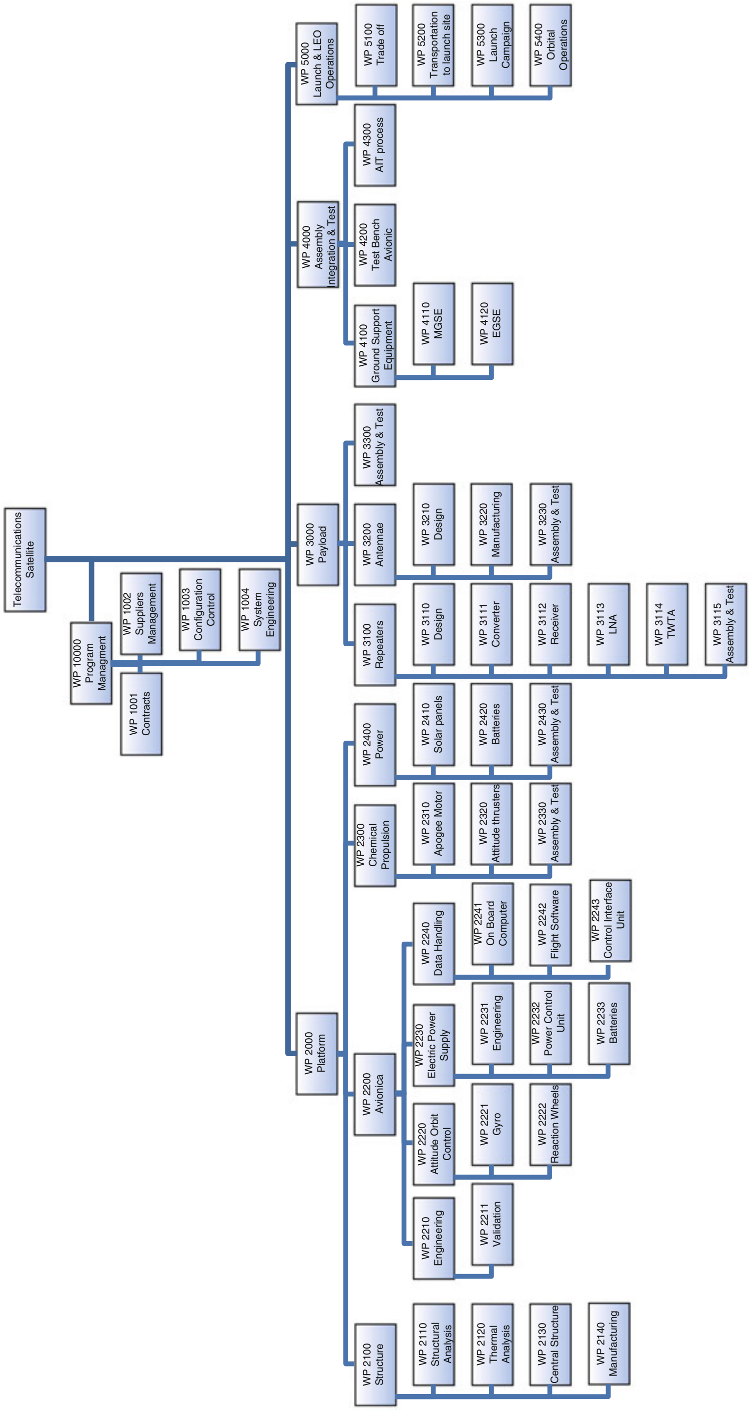


Figure 3.3. Example of work breakdown structure of a telecommunications satellite program.

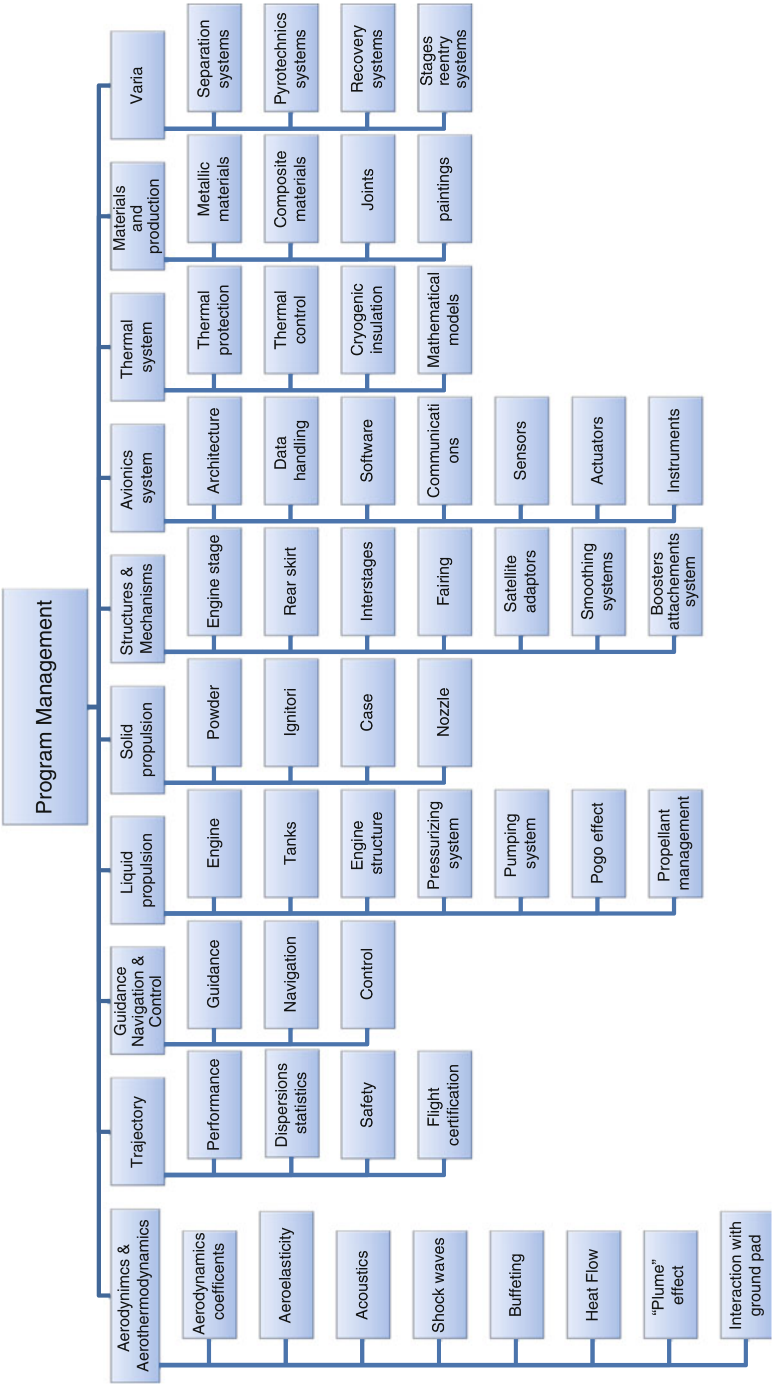


Figure 3.4. Work breakdown structure example/template of a development plan for a space launcher.

Project: WP Title: Contractor: Major Constituent: Start Event: Planned Date: End Event: Planned Date: WP Manager:	WP Code: Sheet 1 of ..... Issue Ref.: Issue Date:

Objectives:

Input:

Tasks:

Output:

Figure 3.5. Example of a work package.

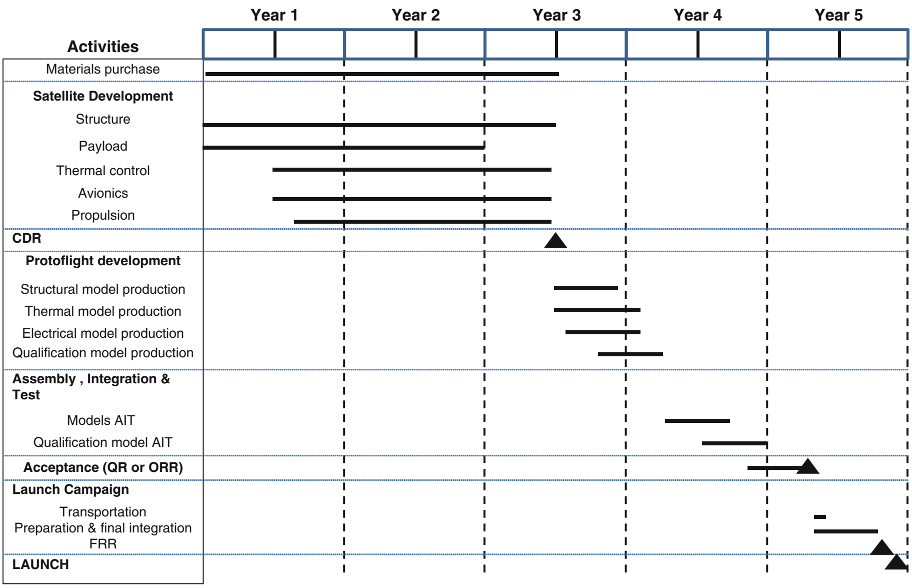


Figure 3.6. Example of program time management planning for a telecommunication satellite.

The program phases logic described in Chap. 2 allows the Program Manager to "update" his own critical path by readapting it with the contingencies encountered, always with the final objective of observing contractual obligations as delivery time schedule and costs.

The last building elements are related to cost which are therefore explained separately in the volume concerning the economic proposal.

COMPANY COST ELEMENT DATA SHEET	FORM No. PSS A1 Issue 2	Page no. _____ of _____
RFQ/ITT no.:		COMPANY NAME:
PROPOSAL no.:		Name and title:
NATIONAL CURRENCY *:		Signature:
Period for which agreed rates and overheads are valid : From__To____		
ECONOMIC CONDITIONS:		

		Status (x when appl.)			
			Agreed by		

1. LABOUR Direct labour cost centres or categories	Basic Labour hourly rate (NC)	Labour OH% (or NC)	GROSS HOURLY RATE in National Currency

2. INTERNAL SPECIAL FACILITIES	Type of Unit	UNIT RATE (NC)

3. OTHER COST ELEMENTS				OVERHEADS %
According to ESA type		According to normal company type		
3.1	Raw materials			
3.2	Mechanical parts			
3.3	Semi-finished products			
3.4	Electric & electron components			
3.5	Hirel parts			
	a) procured by company			
	b) procured by 3rd party			
3.6	External major products			
3.7	External services			
3.8	Transport, insurance			
3.9	Travels			
3.10	Miscellaneous			
3.11	Subcontracts			
GENERAL EXPENSES				
According to ESA type		According to normal company type	Applicable on cost element no.	
5. General & Admin. expenses				
6. Research & Developm. expenses				
7. Other (specify)				
12. COST WITHOUT ADDITIONAL CHARGE				

* No mention of the EURO is required unless the cost accounting system is in EURO in which case the EURO shall be used as the N.C.

Figure 3.7. ESA's PSS form for the detail of cost times.

Figure 3.7 illustrates the standard pricing model of an economic proposal regarding a tender of the European Space Agency ESA, the PSS, and "Price Standard Sheets" which are reference for pricing standards even on a commercial basis.

The various cost items which make up the price are detailed and also the profit, equal to 8% is explicitly recognized and identified.

Figure 3.7 provides an overall view, and Figure 3.8 provides main explanation for compiling a PSS.

INSTRUCTIONS FOR COMPLETING THE COMPANY COST ELEMENT DATA SHEET FORM PSS A1

Form PSS A1 is to be completed by the tenderer and each subcontractor, regardless of the type of price under which the tender is submitted.

PURPOSE

The purpose of this form is to provide the Agency with the basic rates, overheads and general expenses which are subject to the respective companies' normal acccounting method and on which the tender prices have been calculated.

GENERAL NOTES:

(a) It must be expressly stated whether the rates, overheads and general expenses identified are provisional or definitive. The name of the approving authority/institution shall be indicated.
(b) The Agency reserves the right to audit the tenderer's data, submitted in response to this RFQ/ITT.
(c) If for reasons of confidentiality a proposed subcontractor does not want to submit this form through the tenderer he is free to submit it to ESA directly, attention Head of Cost Analysis Division.
(d) Co-contractors are treated as subcontractors for the purposes of this form.
(e) The number of the points below refer to the appropriate number on the Company Cost Element Data Sheet.

INSTRUCTIONS

1. Labour

The basic labour hourly rate, labour overheads and gross hourly rate of each cost centre or category applied to the tender shall be quoted in accordance with the company's normal accounting practice.

2. Internal Special Facilities

Internal Special Facilities refers to the cost of using in-house specialised technical facilities and associated services (e.g. computer, test facilities, numerically controlled machines) for which unit charging rates have been established. The type of unit (i.e. day, hour, minute, etc.) and the unit rate (cost of each unit) shall be shown for each facility.

The rates for Internal Special Facilities shall contain the pertinent overhead, but shall exclude General and Administrative Overheads and General Research and Development Contribution. The two excluded overheads shall be quoted separately under points 5 and 6 respectively. If the unit rates represent established market prices they should be identified with MP in the status column.

3. Other Cost Elements

General

(a) The left-hand column identifies the standard term as applied by ESA. If according to the company's accounting system the elements are named/grouped differently, the appropriate title is to be shown in the second column.
(b) If individual overheads apply to the different categories of other cost, these overheads shall be quoted separately. The overhead shall be quoted as zero, if according to the tenderer's normal costing practice, it is already included elsewhere.
(c) For quoting the various overheads, the definition of ESA cost categories is:

3.1 to 3.5 Materials

As appropriate, the various material overheads are to be shown under the pre-printed headings, i.e. raw materials, mechanical parts, semi-finished products, electric and electronic components and HIREL parts.

For expenditure related to "High Reliability" (HIREL) parts used for space systems, the following special provisions shall apply:

(a) If the HIREL parts are procured by the tenderer for his own part of the work, the usual overhead may be used.
(b) If the HIREL parts are procured by a third party, (i.e. Agent, Prime Contractor) the overheads shall be limited to those overhead activities which are carried out by the tenderer himself.
(c) The overheads on HIREL parts shall only be applicable to the vendor price and shall not be applicable to any Agency charges. Overheads on Agents' services, if applicable, shall be quoted separately under External Services.
(d) HIREL parts and associated overheads may be quoted only by the tenderer requiring the HIREL part for developing or manufacturing his part of the hardware.

3.6 External Major Products

External Major Products are defined as fully manufactured items such as assemblies, devices, modules etc., which are normally produced for other customers by the tenderer or by any other manufacturer and which are intended to be fitted readily, without major processing (machining, modifications, etc.), into the deliverable items, or constitute as such, a deliverable item by itself.

3.7 External Services

External Services are defined as services to be rendered by a third party, such as hire of facilities, computer services, manpower services, plating of parts, services for procurement of HIREL parts etc..

Figure 3.8. ESA's PSS instructions.

3.8 Transport and Insurances
(self-explanatory)

3.9 Travel and subsistence
(self-explanatory)

3.10 Miscellaneous
Any other direct cost elements, which are part of the tender but not covered by the above headings shall be shown with the relevant overhead in this line.

3.11 Subcontracts
A subcontract is a contract to be entered into by the tenderer with a third party for a clearly defined task related to the tenderer's offer and which is sufficiently non-standard that it requires specifications/task descriptions to be generated specifically. It also excludes those elements which fall under a definition contained under Other Cost Elements. A subcontractor can himself place subcontracts. It is thus distinguished from a Purchase Order, which is placed on the basis of standard documents.

4. .

5. General and Administrative Expenses
If, according to the company's normal accounting methods General and Administrative overheads apply, such overheads shall be quoted. Each company shall show on which cost elements the General and Administrative expenses are liquidated.

All ESA non-allowable cost as defined in ANNEX 1, Clause 6.3 to the General Clauses and Conditions for ESA Contracts shall be excluded from the General and Administrative overheads.

6. Research and Development Expenses
The ESA contribution to the companies General Research and Development Expenses is limited to a maximum of 5% of the total Labour cost, Internal Special Facilities cost and Material cost (item 3.1 to 3.5), including the relevant overheads (viz Clause 6.2 of ANNEX 1 to the ESA General Conditions). The General Research and Development contribution shall be quoted separately and shall not be included elsewhere.

7. Other General Expenses
If general expenses other than General and Administrative expenses (item 5) or Research and Development expenses (item 6) have to be borne by the company for execution of the work proposed, the nature of the expenses and resulting percentage of the cost quoted shall be identified against the cost element item.

8. .

9. .

10. .

11. .

12. Cost without Charge
Where the company's normal accounting method defines cost which does not attract any overheads this line shall be used to identify the nature of such cost (e.g. Royalties, Consultancy etc.).

Figure 3.8. (Continued)

Obviously, the Program Manager must have a cost chart for each WP to construct his own costs actively (and therefore the resulting price) and to be able to monitor it during the development of the various activities.

Once the WBS, the WP descriptions, the time management planning and cost data details (the overall Management Plan) have been defined in the offer phase, the Program Manager will have to stick to a tight and constant monitoring of the progress of the program's various activities.

3.5. The Space Program Contract

After the negotiation process has been completed following the presentation of the offer, the contract is signed if the offer has been accepted. The contract clauses are the subject of contract negotiation.

Therefore, an agreement is contracted which creates obligations on both sides, the supplier and the customer.

The obligations, responsibilities and rights of each party, which usually are the only two involved in the contract framework, must be clearly described and specified.

However, there are cases, such as in the contract for Ariane launch services, in which the agreement signed between the parties, Arianespace which supplies the service and the customers, involve third party obligations, in this specific case the French government, should the European launcher taking off from French territory with a satellite of any nationality on board cause any problem to a third territory. Likewise, concerning the European launcher Vega, with a majority of Italian participation, even the Italian state and in a lesser way, ESA, are partially responsible for damages to third parties.

With regard to the unambiguous nature of the contract, both the customer and supplier have a clear interest in not having uncertainties in the agreement.

In fact, the customer must:

- Precisely detail the nature of the program, expressing the technical specifications to assign responsibilities to the supplier.
- Be able to follow the progress of the activities through a detailed calendar of informative steps, for example.
- Provide details of payment modalities in order to design his own investment plan.

While the supplier must:

- Avoid the risk of having the product refused because of noncompliance.
- Have the customer define the nature of the technical control chosen to assign responsibility to the customer himself for accepting the supply of product.
- Know in detail the budget restrictions set down by the payment plan in order to plan for activities.

In any case, as a general rule, we can say a program has been started up only when the contract has been signed.

However, space activities often include contract procedures which for reasons of commercial need or planned institutional funding, involve legal and financial negotiations while technical activities have already been started.

This procedure, usually based on reciprocal trust (in the commercial case, for example, between a satellite operator and a manufacturer who has already realized satellites for the operator) or in a guaranteed institutional framework (for example, in the framework of space agency programs whose funding is already planned) is based on a letter of intent, called the ATP, "Authorization To Proceed" which allows the supplier to begin work and assigns responsibility to the customer through a preliminary order.

In the space market, the types of contracts are standardized, on the one hand, in the framework of the space agencies and, on the other hand, have a looser structure, for example in the commercial market for launch services or for the realization of communication satellites.

Given the sector's specificities, suppliers make up a restricted group on the global scale and their technical competence is generally well known.

Basically, we can identify the following types of contracts:

- Firm and fixed cost
- At cost
- Incentive

Firm and Fixed Price Contract

In the firm and fixed price contract, the supplier and the customer agree to a value of the price, which is definitively established when the contract is signed.

Every WP clearly explains its cost, and in the case of contracts with ESA the margin is in fact preestablished in the making of cost data (called "cost sheets").

The supplier therefore commits to supplying a product for the price established whatever his realization cost might be.

Defining R^0 as the cost of realization estimated at the date of the contract and M^0 as the corresponding estimated profit, the price $P = R^0 + M^0$ can go two ways according to whether the real development cost R is lesser or greater to R^0.

In the first case, the supplier increases his margin and the customer pays more for his work and in the second case the supplier sees his margin decreased and must face program risks (Figure 3.9).

With cost estimate analytical methods the two borderline cases are kept under control and so this type of contract is often used in large space programs.

Should there be unforeseen changes of the contract during the course of the program, or should there be new requests on the part of the customer, or if the supplier considers that for various reasons he cannot meet several contractual obligations, "contract modifications" or "Change Requests" are made. The price is reviewed and the supplier reformulates his price on the basis of contract variation which becomes effective when the parties sign a contract variation called the CCN, "Contract Change Notice."

This type of program is very widespread in European and its use has almost become a standard practice for ESA.

Reimbursement Contract

In a reimbursement contract the expenditures of the supplier are paid by the customer and in his agreement during the work progress, and the supplier's profit, previously defined, does not depend on the final cost of the activity.

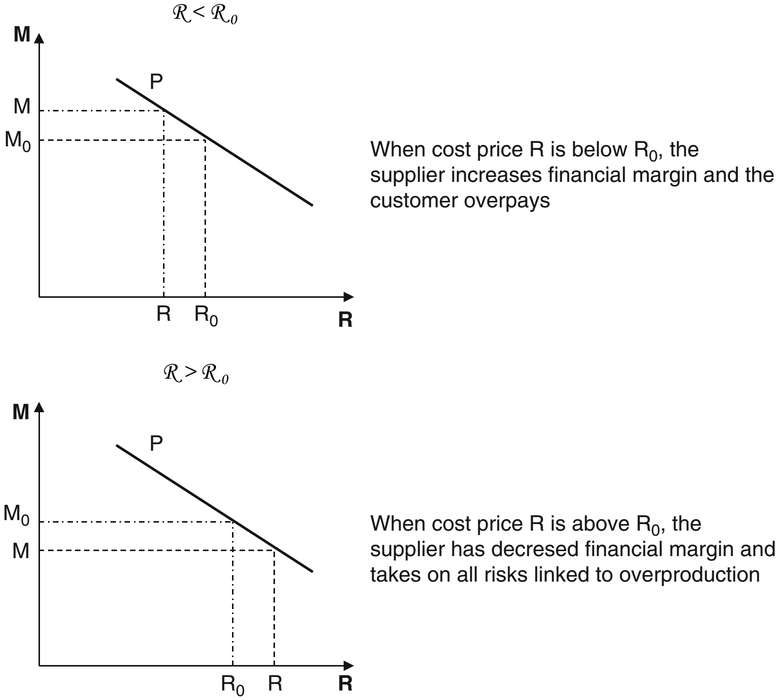


Figure 3.9. General firm and fixed price model.

The supplier commits himself to the best, but the customer reserves the right to verify the basis of an invoice presented and to reject it should it be considered too costly.

From the customer's point of view, the contract cannot be limited to a passive acceptance of invoice with subsequent payment, but rather involves a close critical analysis.

Therefore, this implies that the customer must have a technical and financial structure which can competently evaluate the supplier's operations and for a space program this implies that a customer (for example, a space agency) must have the management resources equal or very close to the supplier (for example, a large industry).

From the point of view of the supplier, this type of contract protects the industry from sudden variations in development costs; for example, the effect of unforeseen technical modifications. The supplier could also find an advantage in increasing costs without an apparent increase of his own margins to the customer, but since an increase in volume of activity also increases the cost of general expenditures, in which the supplier allocates important positions of economic benefit, the general margins increase without involving work teams.

On the other hand, a supplier might not want to increase costs related to the technical improvement of the program, in other words the supplier strives for an optimal relation of price/performance since his margin has been preestablished.

This type of contract is often used when the margins of uncertainty of a program are so high that the supplier, or the customer, estimates unacceptable risk in determining a firm and fixed price.

Its implementation could seem unfavorable at first glance to both parties since the increase in costs could be caused by unforeseen elements. On the other hand, its flexibility makes it a useful tool for managing adjustments during the course of the program by redirecting the necessary WPs more easily.

This type of contract is very widespread in the USA for government contracts, both civilian and military, in which uncertainty margins are sometimes high due to the vast amount of development requirement; for example, the management of a human exploration program or an advanced military technological program.

Incentive Contract

As we have previously stated, it is not a good idea to sign a fixed and firm contract when you have many program uncertainties and the subsequent use of cost contract represents a solution which, however, has the cost of introducing the lack of uncertainties.

However, it is a solution which can lead to overcoming or significantly reducing the progress and efficiency of the program.

This occurs when the incentive formula is used because the firm and fixed price can rise for many reasons, being some risks intrinsically possible; thus this price augmentation is managed on the basis of a detailed verifications of the planned objectives and of the achieved results.

For example, the formula with respect to delivery times is one of the incentive instruments. As a rule of thumb, a contract should respect the time commitments contained in it.

Therefore, such a formula for incentives could appear incongruent.

In any case in space programs, for example the commercial supply of "turn-key" satellites, launch service and ground stations where contract terms are often "tight" due to commercial competition, the customer can often find it beneficial to award the supplier a bonus equal to the delay penalty should the supplier deliver by the foreseen date.

Another type of incentive is based on performance, a goal related to the efficiency of the product requested.

For example, the mass of a satellite or the performance of a launcher can be values indicated in a firm- and fixed-type contract but with a clause that provides a supplementary payment should the dry weight of a satellite be reduced (the mass without fuel).

Plan and Payment Conditions

The payment plan is one of the key elements for the parties because:

- The customer plans the spending of his own resources, capital or debt, according to the modalities of disbursement.
- The supplier plans his activities for developing and acquiring external sources according to the availability of financial resources.

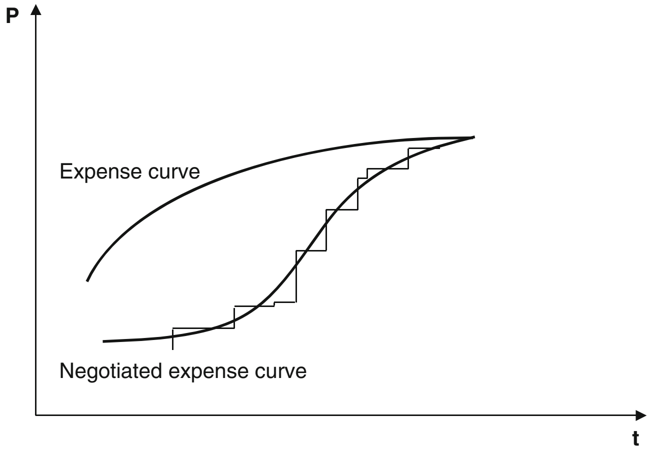


Figure 3.10. Time and expense/payment curves relation.

Therefore, the following items must be defined in a contract:

- The steps technically agreed upon for payments; in general these are important steps in the life of the program, the review or milestones with significant decisions.
- The foreseen dates of these steps and therefore payments.
- The amounts which will be paid by the customer after accepting the product.

In general, the contract negotiation involves two steps, Figure 3.10:

- The time schedule payment profile according to industrial costs and budget availability (expense curve) is defined in the first step.
- In the second step the profiles are adjusted with subsequent repetitions, creating ceilings according to the milestone-time-budget mix (negotiated expense curve).

During the course of negotiation when the two curves tend to decrease their "detachment," we can then put the payment timetable into the contract which indicates:

- The key event for making payment.
- The scheduled date of the key event.
- The amount to be paid at the scheduled date.

Price Review

Contract negotiations are often difficult and complex concerning this point.

In fact, there are financial developments which do not depend on the willingness of either party; for example, the financial variation through the years of the euro and dollar ratio often influences the development of the price foreseen in a contract for realizing a multi-year space program.

The supplier who is committed to a firm and fixed price at a certain date wants to justly guard against the risk related to the above financial development which

can come about at any time once the contract is signed and the scheduled key events.

In addition to the normal insurance procedures against exchange risks which in any case involve a series of added costs to the supplier, there are two possibilities:

- So-called *updating rate* in which the price is realigned with the economic conditions of a preestablished time after the signing of the contract; for example, after 3 months, and then becomes firm and fixed for the remainder of the contract. This procedure is usually applied when the contract will not last more than a year.
- The so-called *revision* in which the price is realigned at preestablished milestones according to revision formulas. This procedure is often applied to long-term programs.

The parameters necessary to the revision are the date when the price is established under the initial economic conditions and the revision formula.

The revision formula is often of this type:

$$P = P^0\,(a + bB/B^0 + cC/C^0 + dD/D^0 + \ldots)$$

where

P is the revised price.
P^0 is the initial price.
B^0, C^0, D^0 are the values of the most representative indices of the elements which made up the price on the original date.
B, C, D are the values of these indices at dates fixed in the contract and is the part fixed by price, that is, not subject to revision.
b, c, d represent the component of various elements making up the price, where $a + b + c + d = 1$.

The definition of the formula therefore gives values to the parameters according to the relative estimates of the programs' various steps towards completion.

Chapter 4

Methods and Tools of Space Programs Management

Before detailing the management techniques of a space program, let us define once more the players who interact during the program:

- The customer: at the most general level, the customer defines the requirements in terms of strategic objectives and specifications. The customer can therefore be a government agency or private company, a national or international organization.
- The agent: frequently the customer, but if he (the customer) does not have all or part of the competences needed for the start-up or the management of the program, these could be assigned to an agent, an administrative or private, who interfaces with suppliers.
- Industrial architect: this could be an industry or a government agency. Because of his recognized competence, he is called upon by the customer or the agent to define the architecture of the overall space system to coordinate various activities and to monitor the realization or production (for instance, in the case ESA for the Galileo program, or especially in the case of the French agency CNES for Ariane launchers).
- The Prime Contractor: an industry or consortium of industries which receive the study and development contract of the program from the customer or agent and who puts the program staff together to develop the program.
- The suppliers who receive contracts from the Prime Contractor to supply devices and subsystems.

Figure 4.1 provides a chart of the contract flow of the players of the European development program for the Galileo satellite navigation system.

In the complex organization put into place for this program, the FOC (Full Orbital Constellation) phase for realizing and launching the thirty Galileo satellites the following structure was configured:

- The European Commission, through Transport Direction, is the customer. After a first phase of government funding provided by the European Space Agency (ESA), the next phase, the FOC, was funded by the European Commission which replaced ESA as the funding agency and therefore, definitively as the customer.
- ESA became a player midway between an agent (which is being increasingly assimilated to the European Commission) and the industrial architect to whom the Commission assigned the task for realizing the system.
- Six industries through targeted contracts act as Prime Contractors for the network of relative activities (space segment, launch services, ground segment, etc.).

M. Spagnulo et al., *Space Program Management: Methods and Tools*,
Space Technology Library 28, DOI 10.1007/978-1-4614-3755-0_4,

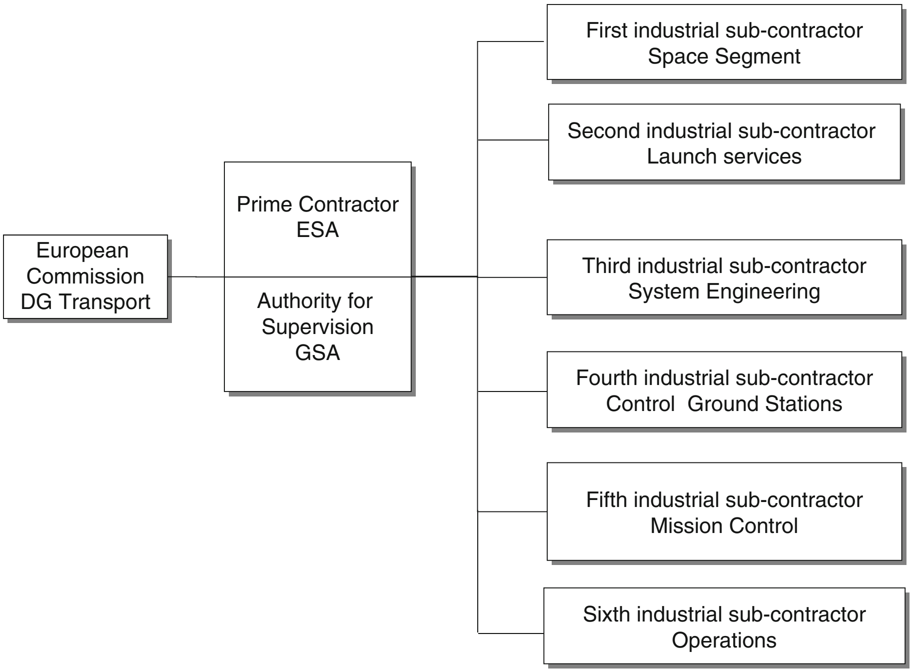


Figure 4.1. Industrial organization of the Galileo project.

- The GSA "Galileo Supervisory Authority" acts as the authority of the European Union to verify the transmission guarantee of the public signal; it is therefore a sort of regulatory agency and controller relative to the supply of the satellite signal.

4.1. Organization of the Program Team

A space program is part of an industrial organization called upon for its realization.

The typical organization of an industry is often based on Business Lines (or Product Lines if it is highly specialized), which characterize the nature of its activities; this organization is a permanent descriptive element, it rarely changes and only when there are significant changes in the firm's strategy.

A program, no matter what its importance and volume are, is limited in time and rarely become directly part of the company's internal organization. Instead, it develops a close network of relationships with the company executive and technical structures.

Due to its peculiar nature, a program is generally part of a high-level decision-making Technical Unit. It is part of Business Lines and directly connected to the company's management.

Matrix Structure of the Program

This type of organization is generally adopted because it allows for the effective management of a program by safeguarding the objectives of the company structure.

The principle of function includes:

- A program team assigned with the management responsibility and therefore achieving the goals of the program. The team, through its leader, the Program Manager, is authorized by management and is directly accountable to it.
- A series of technical units of the company structure which is responsible for realizing activities according to their competence and which therefore act outside the program and have different industrial objectives (even though they generally converge).
- A series of external companies that are assigned various realization activities, which are not awarded a contract within the company structure of the program.

The program team is therefore organized to cover adequately technical and administrative needs.

Figure 4.2 illustrates this type of organization, which can obviously be also applied to the agent as well as to a Prime Contractor.

In a company with a certain amount of repetitive work, for example, a manufacturing industry, which builds many commercial satellites for various customers, many programs can lead to a greater efficiency of the company structure in which several services become common to several programs.

For example, a system team or a Technical Unit of AIT, Assembly Integration & Test, can be created univocally and then be used on an ad hoc basis for each program.

Figure 4.3 shows an example of the possible organization of a program for making a commercial telecommunications satellite.

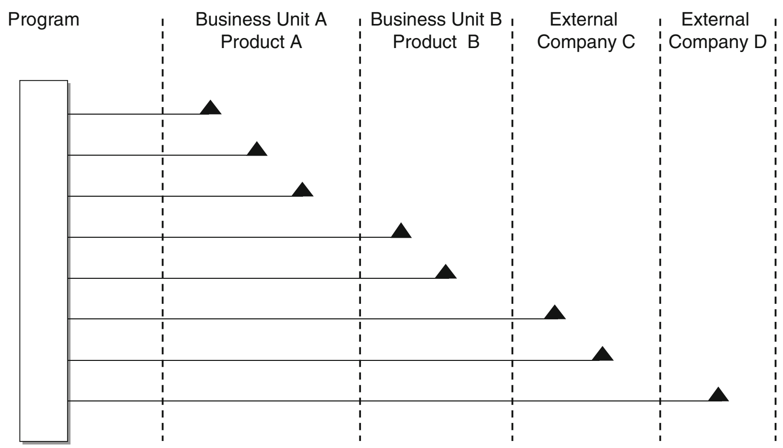


Figure 4.2. Example of the internal organization of a program.

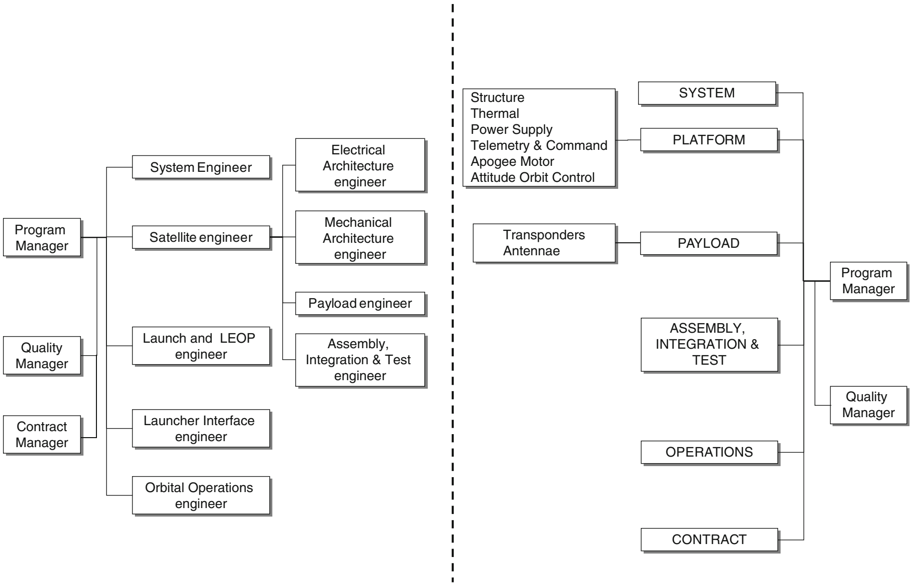


Figure 4.3. Example of a program team for a telecommunications satellite.

The left side of Figure 4.3 shows a possible technical program team structure at Prime Contractor level that includes:

- The Program Manager
- The System Engineer
- A Satellite Engineer who usually directs a team consisting of the manager for electrical engineering, a manager for mechanical and thermal engineering, a manager for the satellite's payload, and a manager for testing and qualification
- A responsible for in-orbit control and LEOP phases, the so-called Low Earth Orbit Phases immediately following launch
- An interface manager with the launch vehicle and related operations
- A quality control manager
- A responsible for contracts and administration

In order not to further complicate the model, on the right side of Figure 4.3 there is the configuration of the general program team configuration alone for realizing the satellite.

The size of a program team depends on its importance, according to its context, the available company resources, and the company structure within which the program is carried out.

On average, a program for a commercial telecommunications satellite has a team made up of at least 15–20 people.

For a large program such as the ISS or Galileo, the team can be made up of dozens of people.

The program team is autonomous and its various managers have an essential role in ensuring the right flow of information and in dealing with unforeseen situations such as technical problems or various administrative matters.

Profiles of Program Team Members

The key resource is the Program Manager who has full responsibility for managing the program under the authority of the company management from whom he receives directives and to whom he reports directly.

With the strength of this authority, the Program Manager must ensure the achievement of technical and financial objectives.

At the technical level, the Program Manager must:

- Have the responsibility reaching overall objectives, ensuring the achievement and coherence of the different requirements that make up the overall program. These activities are mainly the "system management" and the "interface management." In other words, since a program can undergo delays due to the lack of a component from an external source, or even from internal sources, the management of this delay is the Program Manager's task when this problem surfaces.
- Define the tasks and responsibilities of Technical Units without violating the company policy of these units that report hierarchically to another direction/unit.
- Establish the priorities of the program development.
- Define the quality rules and ensure their control.

At the management level, the Program Manager must:

- Respect the overall planning of the program indicated in the Management Plan, beginning with the various individual plans from components to system level, ensuring their development
- Define the measurement of planning control
- Manage the configuration of documentation
- Ensure necessary compromises between the elements of the program, which do not usually converge, such as technical specifications, delays, and costs

At the commercial and contract level, the Program Manager must relate to the customer and ensure the proper ratio of reciprocal satisfaction, as well as to subsuppliers to ensure the proper production flow.

It seems obvious that choosing the Program Manager is a very important decision that the company's administration must take by considering the competences and internal and external context in which the person will have to operate.

A Program Manager must have not only the right technical competences but also and especially wide-ranging knowledge.

A technical specialist background will certainly be a special element, since the person will be able to better understand the viewpoint of the various technical units involved, but he will have to know how to put aside this background in various circumstances in order to reach quick solutions, without damaging the technical quality of the final product.

With the proper spirit of synthesis, a good Program Manager must be able to rapidly understand what is being presented to him and be able to resolve problems, analyzing the real problems from presumed ones.

For example, a technical unit often supplies a device or subsystem with subsequent modifications or improvements that are considered tools for a more efficient product. In these cases, the Program Manager must be able to distinguish when "perfection

becomes the enemy of good," he must be able to reject attractive techniques when he considers that program planning could be impacted in some way because of further testing required or the lack of operational expertise.

Having a humane attitude before a professional one is a necessary requirement for a Program Manager who must motivate, inform, and lead the team with sternness when necessary. These are all qualities that are developed only after many years of technical or management work within complex organizations.

The program team which follows the work, each one with limited objectives, with respect to the Program Manager's, contributes to guiding the Technical or Administration Units towards achieving single objectives; in essence, the realization of the program.

It cannot be denied that for systems and subsystems managers, participation in a complex program is an essential career step, opening the way to solving broader ranging problems that are part of the Program Manager's tasks, thereby increasing knowledge and experience for those aspiring to higher roles.

4.2. Management of Performance and Margins

When a space program is started up, there are a series of uncertainties regarding realization capability that correspond to the management's requirement to adequately provide the final product with the initial requirements and those that appeared during the course of the program.

For example, let us consider the difficulty of accurately predicting the mass at launch of a commercial telecommunications satellite with a ±5% margin at the time the contract is signed for purchasing the satellite. The contract is signed on average 3 or 4 years before the launch and its price depends on the mass of this satellite.

Beginning with the conception and definition phase of a program we tend to seek guarantees which are technically obtained by introducing variations, called "margins," between the nominal value of a parameter (its specific value from requirements) and the one which is considered more probable.

The evaluation of the more probable value can depend on historical elements, from having already developed similar data in the past for other programs or from measuring elements or more often from numerical simulation.

The task of the program team is to define margins within reason neither excessively nor insufficiently, see Figure 4.4 that can be adapted to various program phases.

For example, in the previously mentioned case of the telecommunications satellite, the relative margins of the mass at launch can usually pass from ±10 to ±20% at the beginning of the program to ±1 kg or ±5 kg a few days before the final fuel-up of the satellite tanks, the phase which completes the final ground operations of the satellite and which is then followed by the transport of the satellite to the head of the launcher.

Analysis of the Margins for Different Program Phases

Phases A and B of a space program in which the system specifications are determined will be examined first, the typical conditions of the space segment to be undertaken.

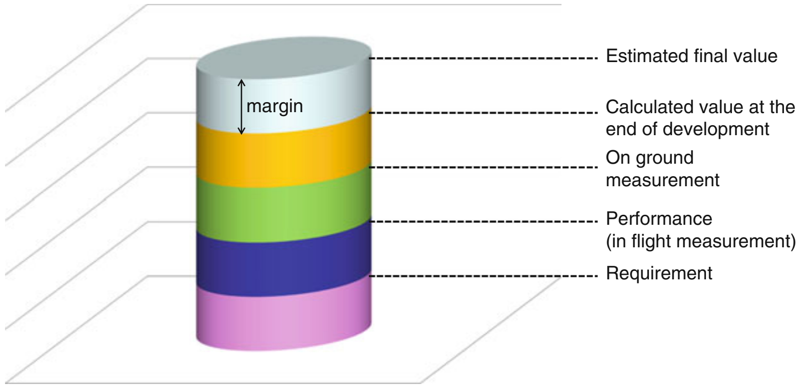


Figure 4.4. Illustration of margins.

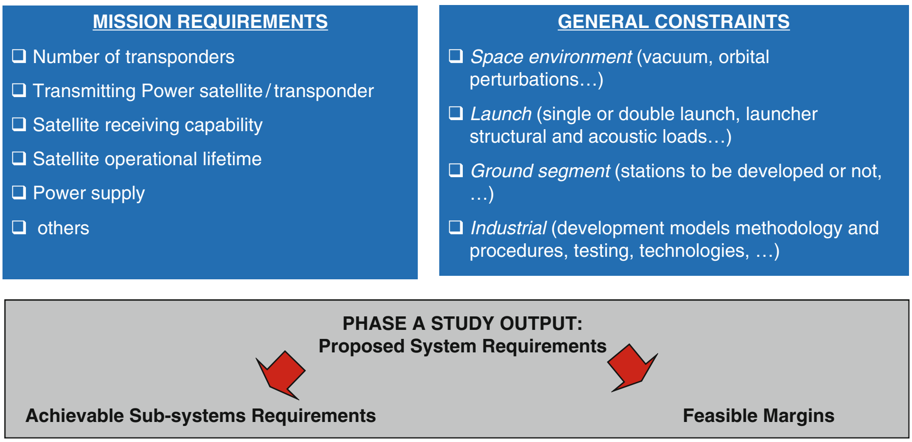


Figure 4.5. Comparison of mission conditions and requirements for a telecommunication satellite.

These conditions essential include:

- Conditions of a space nature; the environment in which the system will have to operate, for example, low orbits with a high level of atomic oxygen or geostationary orbits on terrestrial areas with a strong gravity pull.
- Compatibility conditions with other systems; the management of interface between the satellite and the launcher and subsequent operations to the launch base.
- Conditions of an industrial nature; those relative to technologies to be used or the industrial policy of the nation that funds a space system for government use.
- Technological-type conditions with regard to the research and development needed for the mission to be developed.

A model of the intersection between program conditions and mission requirements is shown in Figure 4.5 concerning a commercial telecommunications satellite as an example.

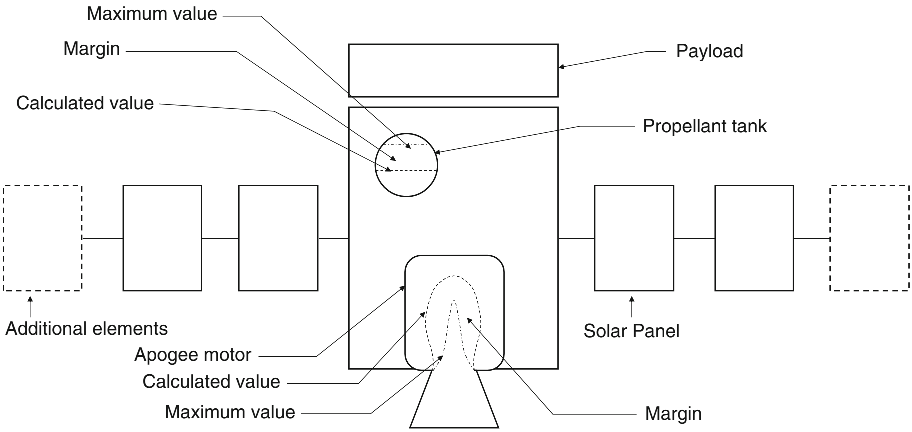


Figure 4.6. Examples of some margins on satellite platform of a telecommunications satellite.

The optimization process therefore requires *technical budgets* on essential elements of the system. In fact, at the start-up of the program the system budgets are defined which determine the key parameters with margins.

Optimization can also be defined as a process that guarantees the adequacy of the margins and has them ideally converge to zero at the end of the program.

In order to illustrate the process, we will consider the case of a telecommunication satellite.

Since it concerns a commercial satellite, the manufacturer has a structure, called a satellite platform that is the basic "chassis" on which to conceive, realize, and integrate the "payload," the panels of radiofrequency repeaters and antennas.

The program mission defines the general specifications in terms of communication capability. This means to know the emitting capability, expressed in watts, of each repeater we must define the right number of repeaters that can be located on the available platform.

We know the maximum mass of the satellite when it is launched which also depends on the launch capability of the launcher (further condition); we know the maximum capacity of the platform tanks and we therefore define the mass budget as the variation between the maximum realizable value and the one calculated according to the structural size of the platform.

Intrinsically connected to the mass budget is the fuel budget, the variation between the possible mass within the tanks and the one calculated according to the propulsion parameters of the motor to ensure the satellite reaches final orbit and then achieves the corrections to stationing for a minimum of 10 or more years.

See Figure 4.6 for a partial series of potential margins to be taken into consideration.

We can also define the available power on board the satellite by optimizing the number of couples of single elements of the solar panels.

By knowing the power of the each couple of elements, the thermal dispersion and absorption capacity of the platform, we can define the power budget as a maximum achievable value and the one calculated as necessary for the functioning of the various subsystems.

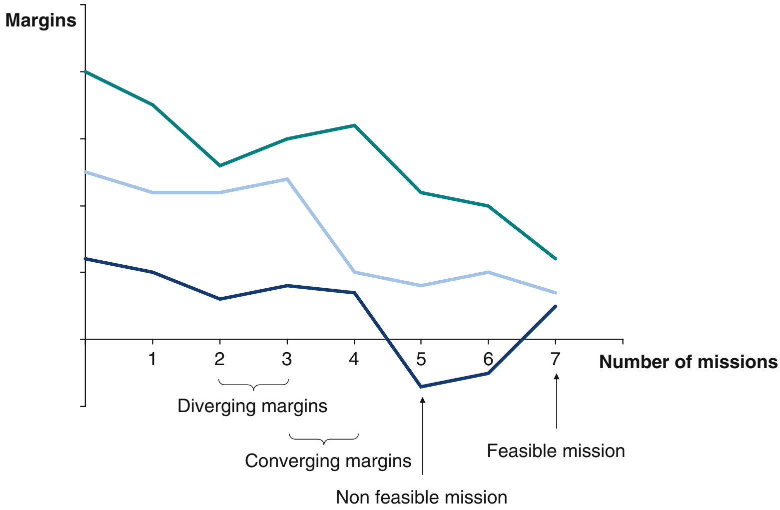


Figure 4.7. Visual parameter analysis of the budgets of a telecommunications satellite.

The process of optimization is done by using these and other budgets, and by essentially defining the optimal number of repeaters, we can simulate various configurations for the satellite, and for each configuration budget are calculated for mass, fuel, power. See Figure 4.7 to visualize (number of repeaters on the horizontal axis) by which number the budget margins are reduced simultaneously.

Sometimes a probability can be connected to the value of a margin or a key parameter; for example, in the case of the satellite one of the mission requirements could be to ensure a margin of 2 dB on the power emitted during 99% of a determined period of the year.

The main system budgets for a telecommunications satellite, the ones that must be defined with appropriate margins, must not become negative since this would cause the mission to deteriorate or to become impossible are the following:

- Mission budget
- Mass budget
- Fuel budget
- Electric power budget
- Communication or link budget
- Number of tele-commands from ground
- Electromagnetic compatibility budget

However, there is a margin with a numerical value or probability value as stated previously for these budgets.

For example, usually a fuel budget leads to optimizing the maximum quantity of fuel needed to have the 99.7% possibility of ensuring the satellite mission for its duration and in this case, the margin is simply the difference between the value calculated and maximum capacity of its tanks.

In this case, the budget can then be optimized to ensure the fuel margin during the orbital life of the satellite, so it does not stop at the realization and launch phase.

In calculating the margins, we often experience difficulties related to the presence of so-called reference levels that come from different sources.

A Prime Contractor of a satellite could autonomously determine its margins:

- According to the technical requirements of the contract with the customer to ensure, for example, a margin on the electric power at the end life of the satellite
- According to the contract requirements but which can be modified and have a financial impact. For example, the increase of the margin for the mass budget at launch is critical for possible increases in price of the launcher, especially during final realization phases
- According to results measured for previous flights; for example in the case of vibration levels measured during launches
- According to state-of-the-art technology

Since a space system, satellite, launcher or infrastructure, can rarely be fully ascribed to previous programs, reference margins are taken into consideration by breaking down the system into subsystems and devices.

With the case of the telecommunication satellite still in mind, the breakdown of various subsystems is parametrically visualized in Figure 4.8 as an example.

A rather practical rule is to apply a knowledge level, from 0 to 5 for example, for each subsystem and to attribute a percentage of error on the estimate or knowledge of the value concerning the subsystem; see Figure 4.9.

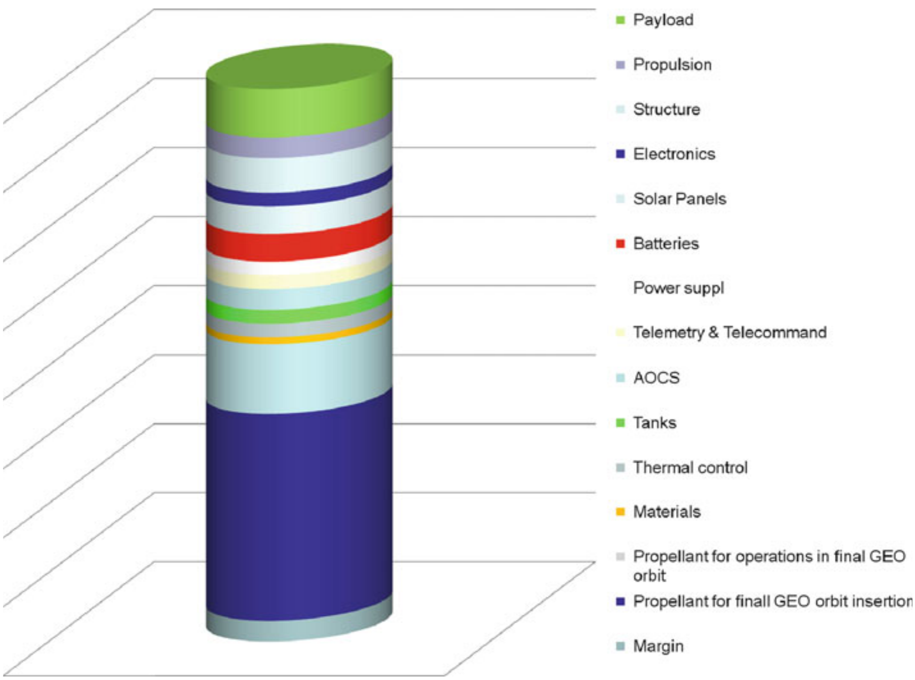


Figure 4.8. Visual breakdown of the mass budget of a telecommunication satellite.

	Confidence level	Estimated mass (kg)	Incertitude (Kg) (0.02 x confidence level)
Payload	4	300	24
Structure	3	200	12
Power supply			
■ Electrical units	2	50	2
■ Solar panels	2	150	6
■ Batteries	2	120	4,8
■ Control electronics	1	50	1
Telemetry & Telecommand	1	60	1,2
Attitude Control	1	80	1,6
Tanks	2	100	4
Thermal control	1	50	1
Apogee motor (dry) including all components for structure	1	80	1,6

End of Life (EoL) satellite mass	M_{FV} = 1360 kg + 59,2 kg
Propellant to be consumed in orbit **(function for lifetime = 0, 2)**	0.2 x M_{FV} = 0,2 x (1360 kg + 59,2 kg)
Beginning of Life (BoL) satellite mass **(EoL mass + consumed propellant)**	M_{IV} = (1360 kg + 272 kg) + (59,2 kg + 11,8 kg) = 1632 kg + 71,04 kg
Propellant mass to reach GEO orbit **(function for circularization = 0, 7)**	0.7 x M_{IV} = [0,7 x (1360 kg + 272 kg)] + [0,7 x (59,2 kg + 11,8 kg] = 1142,4 kg + 49,7 kg
Launch mass	M_L = (1632 kg + 1142,4 kg) + (71,04 kg + 49,07 kg) = 2623,14 kg

Figure 4.9. Numerical example of a mass budget for a telecommunication satellite.

Let us assume:

- A knowledge level 0 corresponds to a subsystem integrally known to which we can ascribe an uncertainty margin of 0%.
- A knowledge level 1 corresponds to a subsystem integrally slightly modified as opposed to the known one, to which we can ascribe an uncertainty margin of 2%.
- A knowledge level 2 corresponds to a subsystem integrally considerably modified, as opposed to the known, to which we can attribute an uncertainty margin of 4%.
- A knowledge level 3 corresponds to a subsystem of new technology to which we can ascribe an uncertainty margin of 6%.
- A knowledge level 4 corresponds to a new-generation device to which we can ascribe an uncertainty margin of 8%.
- A knowledge level 5 corresponds to a new-generation device to which we can ascribe an uncertainty margin of 10%.

We will now consider Phases C and D of a space program during which the system is realized. As we have seen previously in Phases A and B, the management of margins is effected through numerical calculations, essentially simulations, and progressively with measurements as the state of definition and realization of the product allows it.

In development phases C and D, the management of the margins is done with the direct measurement of its parameters and the aid of special documentation, the so-called "configuration," a tool for following its development and for making adjustments.

Figures 4.10 and 4.11 still illustrate the management of budget margins for power and mass budget for a telecommunication satellite.

During Phases C and D obviously, as we proceed towards the material development of the system, margins risk being "confused" with the tolerances or with the project assumptions and this can cause confusion between the supplier and the customer because of various interpretations of the same parameter. This is why it is wise to specify the rules clearly which define the type of system margins in the contract.

In Phase E then, the use of the system in space, the development of several margins, for example, related to the fuel budget, can be checked through telemetry data to plan orbit adjustments to obtain the lifetime duration specified in the contract.

Therefore, at levels of a space program, from the device to the subsystem to the complete system, margins are calculated which contribute to the optimization of the budgets. See the simplified model in Figure 4.12.

It is theoretically rather complicated to produce a system at the end of the program that is perfectly congruent to the project measurement, but it is the objective of the Program Manager to reduce this variation to the smallest degree possible.

In the organization of a program it has already been seen how a program team proceeds downward hierarchically or functionally to the single supplier or device,

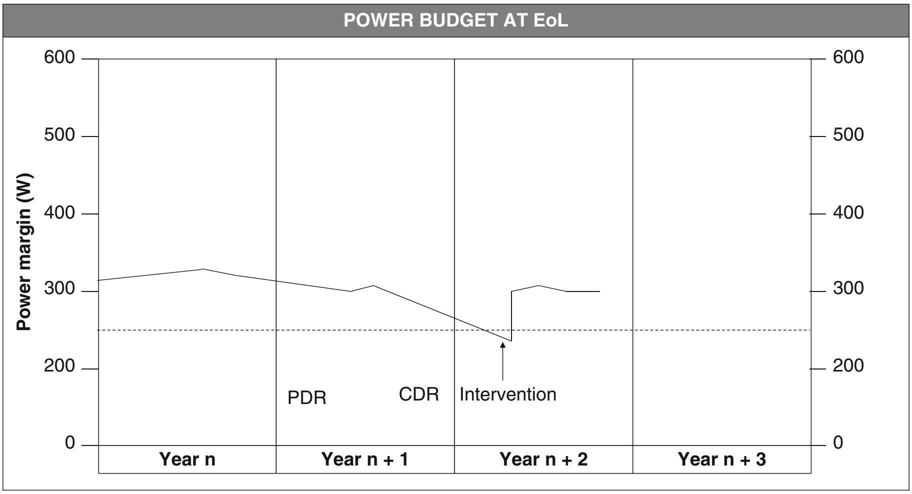


Figure 4.10. Example of the power budget for a telecommunication satellite.

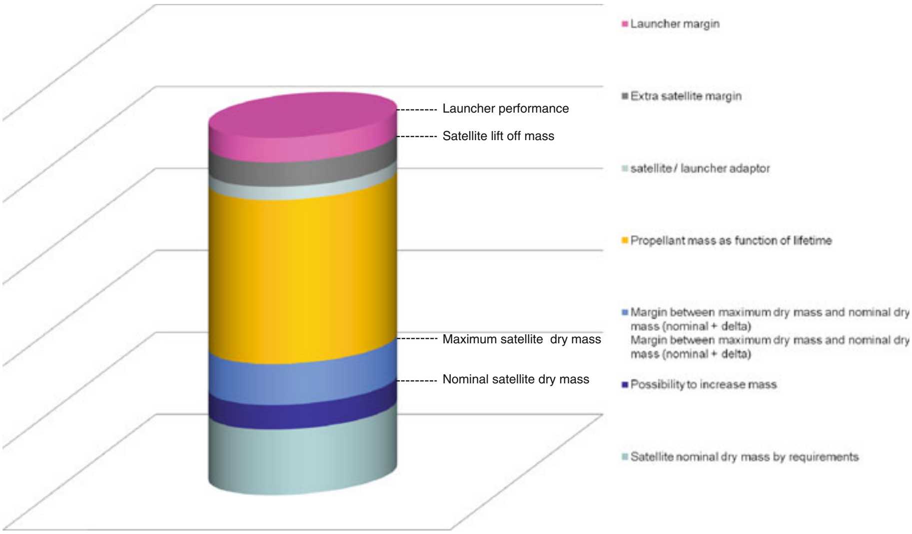


Figure 4.11. Parametric example of a mass budget for a telecommunication satellite.

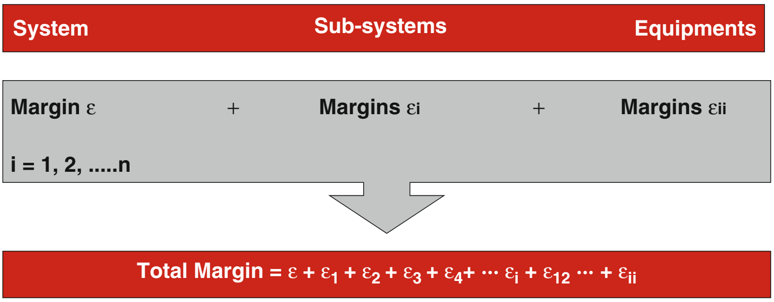


Figure 4.12. Analysis of margin accumulation.

whether they are inside the industrial structure of the program or outside, that is, other companies.

Each manager supplying a device or subsystem will be taking a margin on his own supply that will probably not be known to his hierarchical superior.

This human attitude is completely understandable and universally accepted. In any case, every margin is taken according to different evaluation criteria, often according to the attitude of single individuals who might be under pressure from their hierarchical superiors.

However, as a consequence, there will be an overall margin that is not completely identifiable at the program level, i.e., an unknown variable.

We can then ask the question whether there is a procedure on the part of the program team for sharing these “unknown margins” to redistribute them for the benefit of the entire program.

Realistically this is not possible and in effect the accumulation of these hidden margins is the guarantee every manager at his own level takes on for his supply.

Consequently, the practicality of "margin management" consists in following in detail the development of the key parameters of the program, and especially to adopt choices that are often difficult when we observe the possibility of running into a negative margin.

Let us consider a specific case for a telecommunication satellite to illustrate a practical example for managing margins. If the mass of an encased electronic component were high, we would reduce the thickness of the metallic casing or even change the material of the coating to carbon fiber to lighten the overall weight.

For a subsystem we could decide, for commercial requirements, to increase the margin of the power budget emitted by a repeater on board when the subsystem has already been realized. This requirement could require substituting the coaxial guide between the emission and the antenna with a weaker guide.

We would therefore transfer margins at the subsystem level, increasing the power budget and decreasing the mass budget.

This is an example of the interdependence of the margins and the critical nature of management that must have a profound knowledge of the system to be realized.

At the system level, a further example could be to calculate that even by substituting the guide in the previous case, the power emitted by the subsystem would not be enough to cover the commercial requirement. Should we not be able to intervene, at the level of the subsystem on the antennas, we would need to intervene at the higher system level.

We could operate on the link budget that is also a function of the station-keeping width of the satellite. By reducing this width, the fuel mass should be increased to allow an increase in the orbital maneuvers for adjustment. Consequently, this would increase the total mass budget at launch which, however, will have to remain within the limits imposed by the launcher (unless we renegotiate the price of the launch if there is a significant increase in mass), as well as for the limitations imposed by the capacity of the satellite tanks.

This transfer practice of margins is used frequently in programs. As we have stated previously, it must include a profound knowledge of the system.

4.3. Configuration Management

Configuration management of a space program is aimed at maintaining document control of the technical definition of the system, subsystems, and devices throughout the life of the program. For this reason, the program team will have to produce, maintain, and update all documents that will allow it to have a precise vision of the elements that make up the system they have to develop.

The first function of configuration management is therefore to identify the documents of the specifications and technical requirements.

Since there is a converging time consistency among the various devices/subsystems for the duration of the program, the Program Manager cannot manage this consistency without knowing about its component elements. This is why the second fundamental function of configuration management is planning.

The Configuration manager, inside a program team, will thus have to establish, in accordance with planning, a parallel path of control and verification of the documents

to allow the team to be able to identify the technical status of the system, subsystem or device, at any given moment of the program.

The third function of Configuration management is the control of the configuration status itself, that is to follow the development of the program elements through previously authorized subsequent modifications that have had repercussions on the program.

Identification, planning and control, and lastly the verification and insertion of developments or modifications make up the three essential functions of configuration management.

Methodology of the Configuration Management

Identification Function

This is accomplished by drawing up specific technical documents, controlled and numbered in configuration, and which are slowly updated during the course of the program and are approved at decisive moments such as the review.

The Configuration of each element, from the devices to the entire system, must provide for a series of documents including, at the least, the following:

- Technical Specifications (requirements)
- Definition Document or DD
- Production and Control Document or PCD
- Interface Control Document or ICD

Any element can be identified when we have these documents, which in synthesis allow us to trace the history, development, modification, and current status at the end of the program. Of the four documents, all of them equally important, the DD and the ICD are of particular relevance.

In the DD, the system to be realized is broken down into all its components and identified, while in the ICD all the relationships among the components of the system, both internal and external program elements, are taken into consideration.

Figure 4.13 shows an example of a possible index for a DD of a telecommunication satellite program.

The Interface Control Document is usually made up of two parts:

- The first part, drawn up by the customer, defines the system interface with the external world, for example, laboratory tests, assembly rooms, launch base. Various features are clarified, such as:
  - Axial reference systems
  - Obstruction volumes under the launcher fairing
  - External feeding connectors under the launcher fairing
  - In-orbit configuration
  - And so on.
- The second part, drawn up by the Prime Contractor or the program team, defines the consistency of the system with the specifications. Basically, starting with the data from suppliers, for example, mechanical, thermal or structural models of a device, the Prime Contractor or the program team verify them with their integration at system level, both possible and consistent.

A – GENERAL ISSUES

- Material definition and identification (synthesis of design data for sub-systems and equipments with technical reference number)
- Applicable documents
- Status of Configuration (preliminary, final, …)

B – SATELLITE GENERAL DESCRIPTION

- Sub-systems functionalities
- Deployment plan
  - Preparation to launch
  - Orbital configuration
- Development Plan

C – TECHNICAL CARACTHERISTICS

- Functional
- Performance
- Physical

D – ARCHITECTURAL DESIGN SCHEMES

E – BUDGETS

- Mechanical (reference axes, mass, inertia, alignment)
- Thermal
- Power
- Telemetry & Telecommand
- Orbital accuracy
- Links
- …

F – ORBITAL MANEUVERS

- Operative modes
- Procedures and constraints among operative modes

G – LIMITS & CONSTRAINTS

- Life duration
- Security
- Transport and maintenance

Figure 4.13. An example of an index for a Definition Document for a telecommunication satellite.

This must be further validated by the supplier.

Once it has been determined, the Interface Control Document becomes a "technical specification" and is therefore the object of a formal and accurate procedure for Configuration management.

An example of a possible index of an Interface Control Document for a telecommunication satellite is provided in Figure 4.14.

a) Volume 1: Mechanical Interface Control Document

(i) – SYSTEM

- Configuration
  - Reference axes system
  - Mass
  - Orbital configuration

- Launcher interfaces
  - Inside fairing
  - On launch pad

- Development
  - Equipment development plan
  - Wiring development plan
  - Other details

- Budget for mass-inertia-alignment

- Visual inspections

(ii) SUB-SYSTEMS & EQUIPMENTS

- Mechanical data:
  - Maximum external dimensions
  - Detailed interface dimensions, including holes and tolerances
  - Reference axes definition
  - Mass
  - Center of gravity position, Inertia
  - External surface treatment

- Electromechanical data
  - Identification and positioning of electrical connectors
  - Code and name of connectors suppliers
  - Number of pins

b) Volume 2: Thermal Interface Control Document

(i) – SYSTEM

- Orbit analysis
- Orbital phases
- Functioning modes
- General architecture for thermal sub-system

(ii) SUB-SYSTEM AND EQUIPMENTS

- Interface
  - Conductivity
  - Radiation
- Mass
- Thermal capacity
- Internal thermal resistance
- Dissipated power (minimum, nominal, maximum)
- Acceptable temperatures (min & max) at interfaces
  - In orbit (operative, safe-mode)
  - On ground

Figure 4.14. Index example for an Interface Document for a telecommunication satellite.

c) <u>Volume 3: Electrical Interface Control Document</u>

(i) – SYSTEM

- General architecture of electrical connections
- General architecture at "0 Volt"
- Power supply general architecture

(ii) SUB-SYSTEMS

- Power requirements
  - Primary source
  - Secondary source
  - Per functioning mode
- Interconnection plan
  - Definition of internal equipments and interconnections
  - PIN, wiring
  - Connections among sub-systems

(ii) EQUIPMENTS

- Typology and code of connectors
- Number of pin
- Nature and functionality of PIN signal
- Signal characteristics
- Level of ampere inside the PIN

d) <u>Volume 4: Telecommand Interface Control Document</u>

(i) – SATELLITE

- List of telecommands
- Different types of orders and characteristics

(ii) SUB-SYSTEMS AND EQUIPMENTS

- Name and destination of the command
- Typology of command
- Functioning phases when command is required
- Verification from te lemetry (if applicable)

c) <u>Volume 5: Telemetry Interface Control Document</u>

(i) – SYSTEM

- List of telemetries
- Description of signal format
- Typology and characteristics of signal

(ii) SUB-SYSTEMS

- Signal name
- Type of signal
- Frequencies for digital selection
- Formats
- …

Figure 4.14. (Continued)

Planning and Control Function

Control involves overall procedures that define the situation of the

- Approved documents at every review
- Formally control the configured and approved documents through management system of the modifications made, which according to their categorization (category 1 equals "major" modifications, category 2 equals "minor" modifications) must be approved by the customer and the program team
- Control with the appropriate internal procedures the development of the technical documents as long as the modifications have not been formally approved and consequently the Configuration remains "frozen at status"

The process can be assimilated to a progressive acquisition of the Configuration, whose development is reported during the key reviews of the program.

This process definitely appears at the formal reference registration of the documents established for the Identification. Their access is regulated by the original version of each of them. In this way, each document can only be modified under the sole responsibility of the person issuing it and without a written and catalogued evidence of the document, which caused the development. Usually the procedure is performed in agreement not only with the customer, but also with the involvement of the suppliers.

Figure 4.15 provides an example of the possible acquisition planning of the configuration for a satellite.

As we can see, the document list is cross-indexed with the temporal sequence of the program reviews and according to the type of review we can have a picture of how Configuration management evolves in time.

As stated previously, during the course of the program's duration, the reviews must be established to effect:

- An in-depth evaluation of activities
- An analysis of the documentation drawn up or the testing results taking into charge of review group recommendations
- A status freeze of the Configuration

Management procedures of Configuration can be divided into:

- Internal management which refers to the management of documents of each single player and which is not under the control of the program team (for example, a Technical Unit that realizes a device for the program)
- Formal management of the configured documents that is the responsibility of the program team

At this point we can illustrate the developments of the Configuration documents by examining Figure 4.16, which refers to ESA's standard procedures concerning the program's document list.

The documents are formally managed at the end of the reviews, which are updated in the Configuration.

The updates can be implemented during contractually defined key moments but which generally coincide with program reviews.

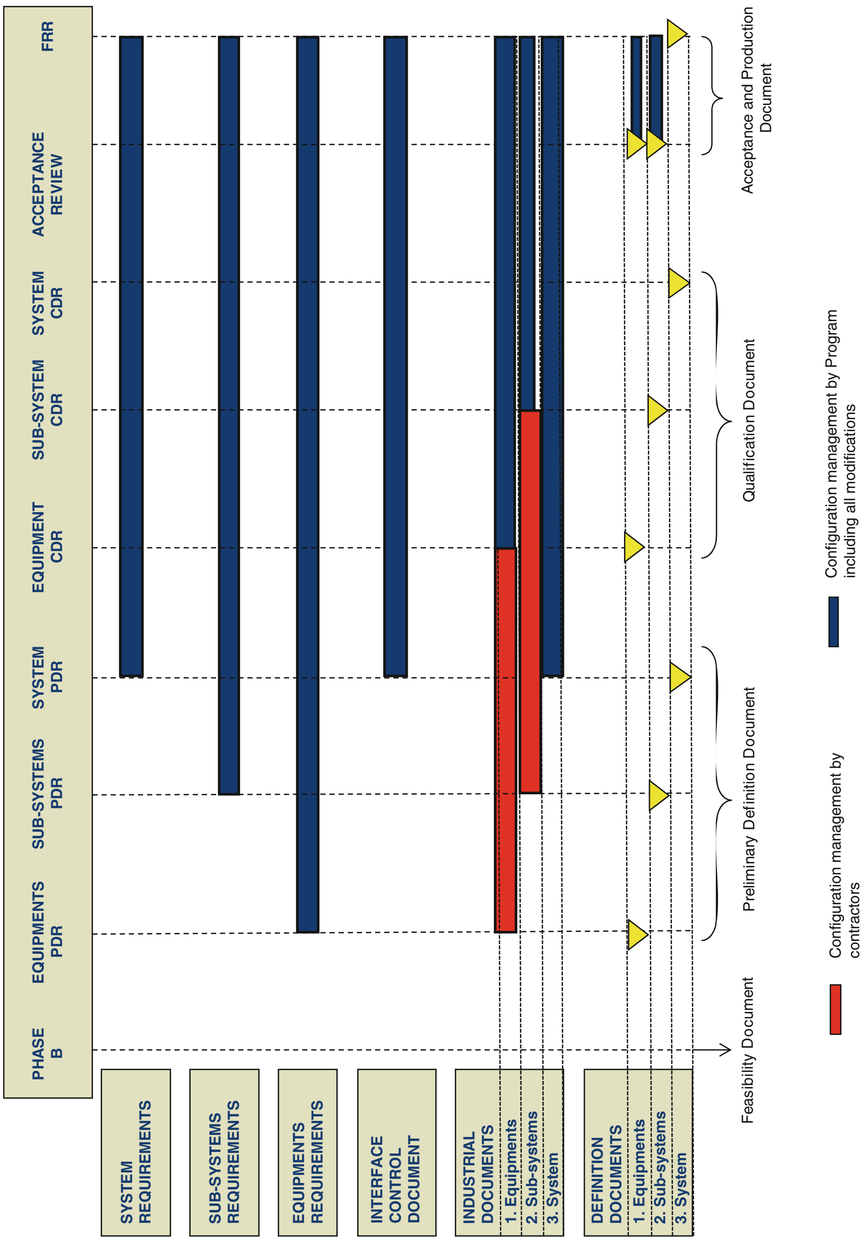


Figure 4.15. Example of the development plan of configuration for a telecommunication satellite.

Documents	**MDR**	**PRR**	**SRR**	**PDR**	**CDR**
Functional System Requirements	issue 1	final issue			
Technical System Requirements	issue 1	final issue			
Requirements Justification Document	issue 1	final issue			
Mission Feasibility Study	issue 1	final issue			
Management Plan	**Issue 1**		**revision**	**final issue**	
Requirements & Specifications Document		issue 1	final issue		
Product Assurance Plan			issue 1	revision	final issue
Definition Document		issue 1	final issue		
Interface Control Document			issue 1	final issue	
Configuration Control Document			issue 1	final issue	
Assembly Integration & Test Plan				issue 1	final issue

Figure 4.16. Development of Configuration documents according to ESA standards chart.

Verification Function and Insertion of Modifications

Verification and insertion of modifications therefore renews the status of the Configuration and are carried out:

- By listing the type and state of approval of the proposed modifications by various leaders, by industries, program team, or the customer
- By physically introducing reference documents of the Configuration the modifications and their state of approval

The final objective of the process is also to precisely know, before qualifying during a relevant review, a device, subsystem or a system, the theoretical Configuration and the realization differences of the product with regard to the theoretical Configuration.

An essential aspect of Configuration management is the classification of the modifications that must be formally approved or rejected according to precise procedures.

Usually, the modifications are classified into three types:

- Category 1: modifications that have an impact on the technical or contract specifications established in the "base" contract, that is, between the customer and the Prime Contractor
- Category 2: which have an impact on the technical or contract specifications between the Prime Contractor and the subsuppliers and which therefore do not influence the "base" contract
- Category 3: modifications which can be effected by a subsupplier to fulfill the technical requirements he is requested to fulfill

The process of proposal and acceptance/refusal of the modifications is managed in a formal manner. Each modification proposal is therefore processed according to standards that can vary in different programs; however, the illustrated chart in Figure 4.17 represents its main features.

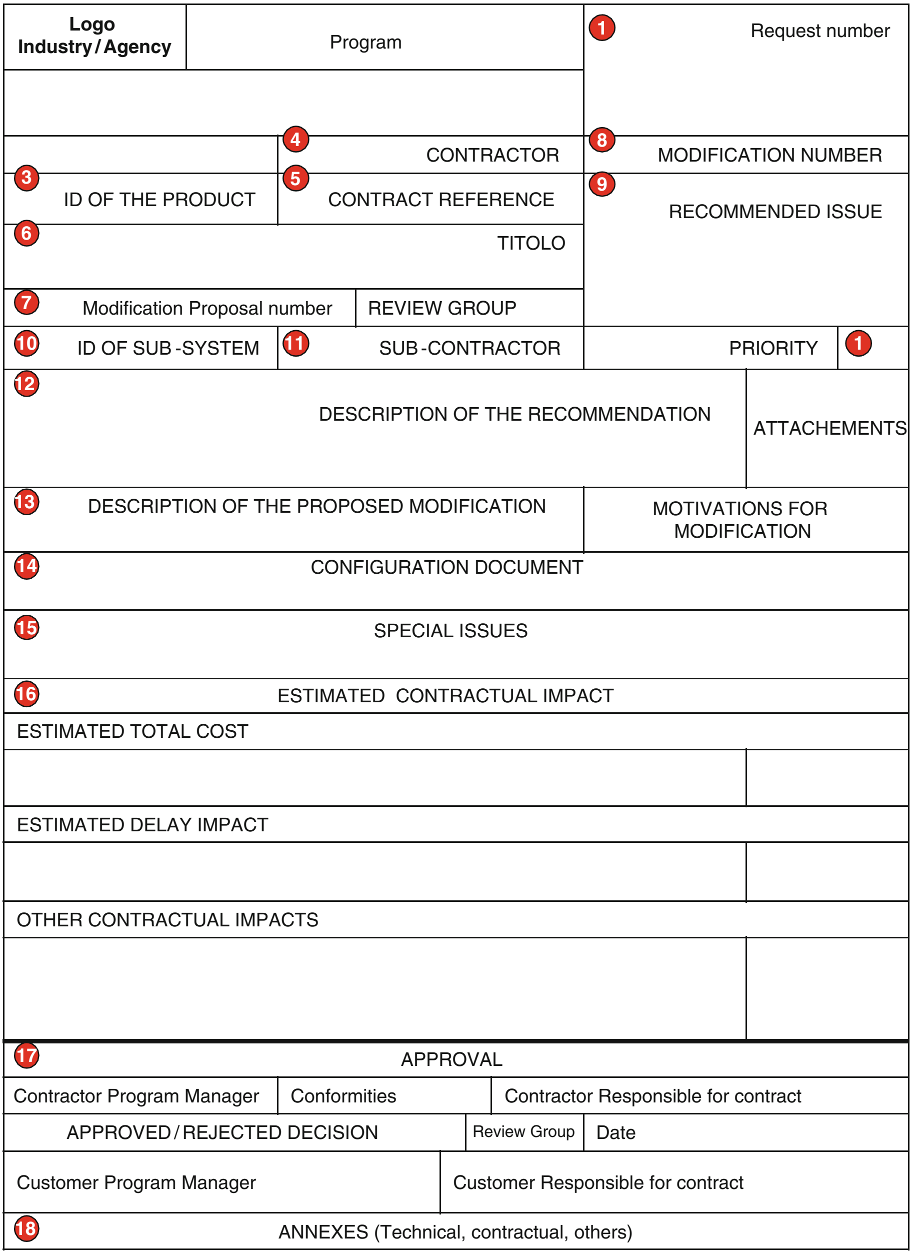


Figure 4.17. Example of a program modification proposal.

In principle, every modification proposal should contain at least the following elements:

- The number of modification proposals
- The agency that proposes it
- The impact of the modification on the documents managed in Configuration
- The technical justifications of cost and time impact

The modification proposals are examined on two levels: firstly the program team or the Prime Contractor, and secondly by a relevant committee in which the program team with the customer analyzes the modification proposal and who jointly decree its approval or refusal.

The process is similar to the closed control loop.

The approval can be total or partial, in the sense that a modification can be accepted but in a limited way to a single device, for example, and not by the entire subsystem as originally proposed.

In each case the responsibility for the incorporation of a program modification must always be communicated to and accepted by the customer.

4.4. Assembly, Integration, and Test Management

In the management of space programs, the activity dedicated to tests is fundamental for ensuring the convergence of the program to the originally defined mission requirements.

The convergence is therefore expressed not only through numerical simulation but also especially through true physical testing of the program elements, devices, and subsystems up to the system.

All the hardware and software of a space system is tested and measured at the level of:

- Elementary components
- Equipment or devices
- Subsystems
- Integrated systems
- Interface with external elements

Naturally, according to the type of the mission, the planning of the testing can be different.

In fact, it is evident that the nature of certain programs such as the scientific probes or space systems with astronauts on board differs in complexity and redundancy with respect to space launchers or commercial telecommunication satellites. This can lead to very different types of tests according to the varying criticality of the required verification.

Types of Tests

The tests must verify the operational and functional conditions of the system elements according to their performance for which these elements were designed inside the system itself.

The tests can therefore satisfy these types of verifications:

Functional

This type of test is done with measurements, electric or radioelectric simulations usually in a laboratory or during testing under thermal void. The functional verification of the various subsystems is almost always performed in an integrated fashion with a test of electromagnetic compatibility. These tests are performed with appropriate test benches whose specifications and realization are the responsibility of the program team.

Environmental

This type of test is performed to verify the compatibility of system elements with onground operations before the launch; then with the launcher during the putting into orbit phase; and finally with the space environment, the location of the operations.

Concerning ground operations, we must keep in mind that all the material will have to be realized, stored, worked, and transported on Earth before flying into space. Therefore, every element will be subject to transport and handling which will require establishing conditions and restrictions in detail.

Concerning the launcher, the tests will have provided the verification of mechanical, structural, acoustic, and electromagnetic compatibilities of the system with the noise and vibration conditions caused by the launcher. These conditions are usually well known and are described in the "user's manual" of various launch vehicles. These tests are performed with both numerical simulations and with physical testing and mainly concern:

- Mechanical and acoustic vibration tests
- Shock tests or transitory acceleration test
- Static tests
- Inertia equilibrium tests

Concerning the space environment once in orbit, the tests to be carried out on ground involve verifying the system's resistance to thermal conditions in the cosmic void with and without solar radiation. For telecommunication satellites in geostationary orbit, the verification test of the electrostatic charge and discharge is of major importance given the fact that sidereal irradiation is not decreased by the Earth's magnetic field or by the layers of the atmosphere. These tests are performed specifically under void and in thermal testing laboratories.

Interface

These tests, conducted through simulations, concern compatibility testing with other systems, such as compatibility of communication between the satellite in low orbit and the onground station network for communications and control.

Generally, testing philosophy for space programs tends to realize a prototype model of the system (satellite, spacecraft, or infrastructure) identical to the in-flight model to perform qualification tests with definite margins.

This method usually ensures the best performances even in orbit but can present, according to the program, the disadvantage of requiring greater development cost and more time.

The testing plan can be reduced; for example, in the case of pseudo-recurrent program, i.e., programs whose system uses platforms or subsystems already used in previous programs and therefore well known at a functional level.

However, in general, a test plan is established at the time the system is conceived for the very reason the availability or not of adequate test means significantly influence the choice of the project.

In general, the program first asks specific questions before establishing the test plan, such as what type of test is foreseen for a given element, and at what point of its realization? Which margins apply on the various tests that we want to carry out? What are the most adequate test instruments for verifying we wish to perform? How can we be sure of the accuracy of the tests and therefore manage the quality of the instruments and measurements?

Test Planning and Methods

Even the planning of tests for a space program is a formal process that must be defined at the time of its conception and is part of the Management Plan.

The tests are planned by defining the relative technical documentation (specifications, planning) and control documentation (control, measurement, and conformity plan).

Figure 4.18 illustrates the relative logic for planning tests.

The logic that guides the definition of the test plan is in practice a methodological synthesis of the verifications of the system's various levels to be as certain as possible that the material produced responds to specific requirements.

Obviously, there is a necessary compromise in choosing tests with the reliability, financial, customer, and condition requirements imposed by the market and by the competition.

Planning tests and the subsequent process of verification begin from the preliminary design phase and extend to the final acceptance through an articulated interaction on many levels, from devices to subsystems to the final system. An interaction can take place in three main phases: the Design Qualification, the Performance Qualification, and the Acceptance Qualification.

Design Qualification is established during the initial development of the program and consists in verifying the idea of the mission and the evaluation of various options of the system for realizing them.

In general, the highest level of testing up to the subsystem and the testing of development regarding essential devices or subsystems of new conception or production occur during Design Qualification. The program team can even decide that for these devices or subsystems a simple verification by numerical analysis rather than a physical test might be adequate.

Sometimes, several Design Qualification physical tests can lead to the material breakdown of the device itself to verify its degree of resistance and change margins as a consequence.

The Performance Qualification is performed on representative models of flight and the tests are therefore realized at the highest level of representation for the system, therefore integrating subsystems and devices functionally. Usually in this phase the payload of the tests is often greater than the one considered maximum during the

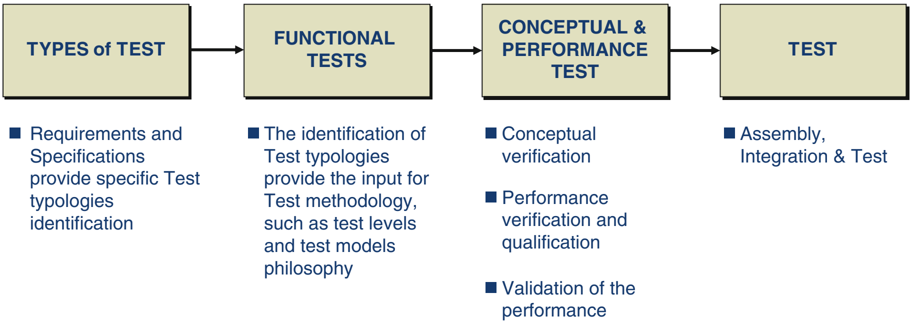


Figure 4.18. Example of the logic for planning program tests.

orbital life of the program. For example, tests of electromagnetic radiation or vibration are superior to the maximum estimated levels in orbit or during launch. This is done to verify the extreme limits of functioning without, however, damaging the global performance of the system.

The guiding principle is to look for the maximum level of possible defects to the minimum level of the device and subsystem in order to minimize the risk of having defects in flight that will affect the system level.

Proto-Flight Models, i.e., PFMs, are often realized. They are testing models that are destined to be flown in orbit. In this case from the first development phases, rigorously analytical qualification tests of the device to the system are adopted.

The Acceptance Qualification is performed on flight models, called Flight Models or FMs, and is made up of functional, environmental, and performance tests realized at higher levels from those estimated during the life of the program, from onground development to the launch to orbital life. The goal is to test the entire system and to ensure that it is reliable and without manufacturing defects.

There are different test methods: for numerical or simulation analyses, for tests, inspection, similarity, and demonstration following a program review.

The analysis or simulation methods include all the techniques of verification elaborated from mathematical and calculation models that represent the system and subsystems or even devices.

These methods are, however, always complementary and never substitute those of direct testing. They can become alternatives to testing if they are judged economical and can supply a high level of reliability or can be done when a physical test is impossible to perform on ground.

With the development of mathematical models following the increase in capabilities of calculation, the analytical tests are becoming an increasingly used method of verification for the system and subsystem to evaluate the phases of function under different operational environments.

Methods of testing for proof are performed for the qualification of a product, of a subsystem or a system, for their acceptance on flight and are distinguished by:

- *Functional tests*, performed in normal environments that are essentially compatibility, interface and function tests for verifying electricity, mechanics, electromagnetic, radioelectrics, etc.

- *Environmental tests* as opposed to functional ones have induced external conditions such as vibrations, temperature variations, and different levels of radiation. Even these tests are performed at all levels, from the device to the system, and they are aimed at reproducing the environment in which the system will be found as much as possible during launch and orbit life.

Test methods for inspection are made up of the visual examination of the different components of a system element, from the subsystem to the device and are therefore usually used on ground in Quality Control processes. However, tests in orbit for inspection are used in verifying the thermal shield of the Space Shuttle or for verifying the physical state of external elements, for example, the solar panels of the International Space Station ISS.

Test methods for similarity are performed in case a device or subsystem cannot be used by a program directly, but can be reused in another program.

This often occurs in commercial programs in which the spacecraft platform is always the same size for economic requirements.

Obviously, even in these cases, the Performance and Acceptance tests must be rigorously performed.

Verification methods following program reviews involve accepting a material based on documentation and tests produced during the review to declare their compliance with the specifications of the material and there is no need to proceed with further tests. Usually this procedure is performed at the level of device or subsystem and essentially concerns an Acceptance Qualification.

Once the different test methods have been examined, it will be necessary to define the models to which determined levels of verification are applied.

For example, at the device level, verification is performed on circuits or bench models, available in series or integrated with elements developed specifically for the program. Usually in commercial programs, the qualification of a device is performed at the same time as acceptance, even if it can carry risks that in any case are not taken in noncommercial programs.

An approach that describes the philosophy of models for tests tends therefore to define at the beginning of a program the nature and number of these models to define the functional analysis they are to undergo.

This approach is often dictated also by the available financial budget, by the duration of the program and the experience of engineers of the program team.

Figure 4.19 illustrates the main models and subsequent financial analysis for verification and testing.

The detailed analysis of the combination of various models, from device to system, leads to the determination of the testing cycle for qualification and acceptance.

In a space program, the above-defined process is called AIT, Assembly Integration and Test, and makes up a very important phase in the life of the program since, as is illustrated by the logic model of Figure 4.20, its development is a function of feedback from initial design phases to the mission itself.

The final objective of the AIT is to minimize costs and therefore the number of models, ensuring the rigorous level of technical confidence of the final product.

There are various AIT philosophies. For example, one envisions the development of a preliminary model, Development Model, followed by a Qualification Model, and

ITEMS	DEVELOPMENT	QUALIFICATION	PRODUCTION
Equipments	EEM: Electrical Engineering Model	QM: Qualification Model EQM: Engineering Qualification Model (only ground model)	FMi: Flight Model (i = 1, …, n)
Sub-systems **System**	SM: Structural Model (in scale) TM: Thermal Model (in scale) RM: Radio electrical Model (in scale) EM: Engineering Model	PFM: Prototype Flight Model (usable in flight)	
CLASSICAL PHYLOSOPHY : EEM + QM + FM **ALTERNATIVE (1): EQM + FM** **ALTERNATIVE (2): EQM + PFM**			

Figure 4.19. Example of models from development to acceptance for flight.

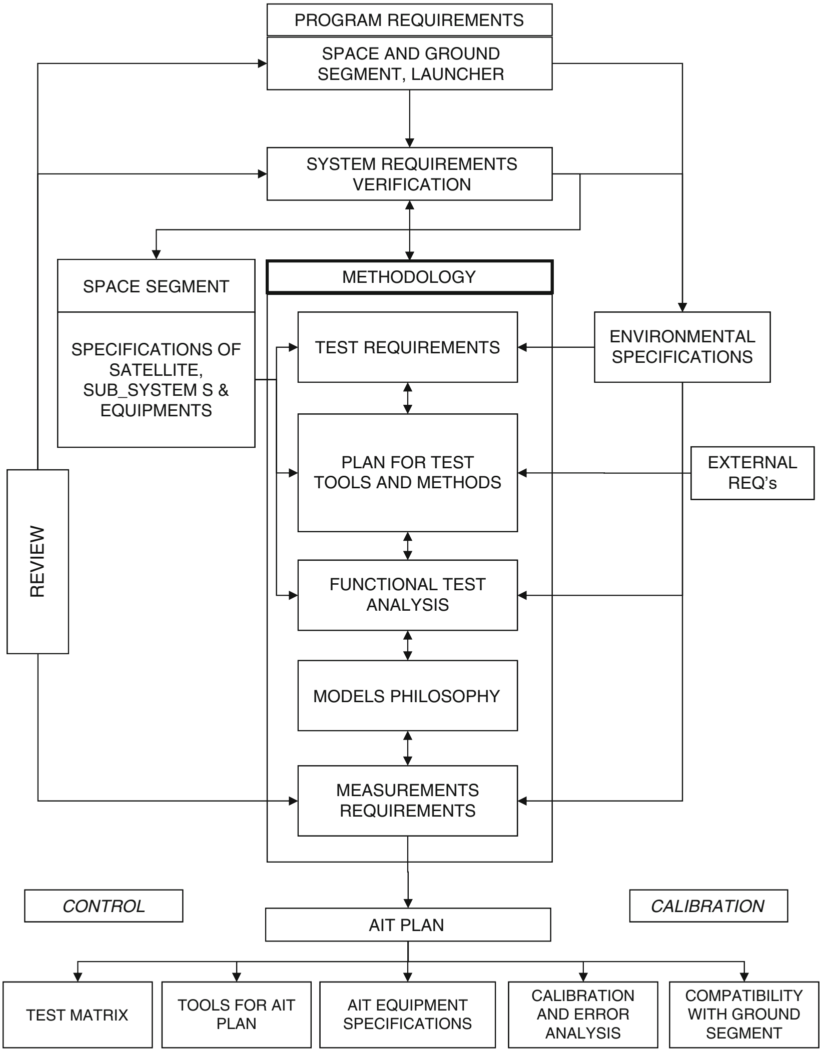


Figure 4.20. Functional model of the test program logic.

then a Flight Model or one that envisions the development of a flight prototype, ProtoFlight Model, and then a Flight Model.

There are no precise rules, but in general it is necessary to be rigorous at the device and subsystem level and then to verify the function of the integrated system.

Test planning, the AIT Plan, is therefore a document of primary importance which is drawn up under the responsibility of the program team from the offer phases to the customer.

The verification program is detailed in it for all the models foreseen and is applied to Phases A, B, and C/D of the program. The logical flow of this process is illustrated schematically in Figure 4.21a–c applicable to the program phases.

Test Tools

Once the AIT Plan is defined, we proceed to examine what are specifically the means, testing instruments, used for the AIT, since knowing them allows us to make up the decisive decision-making processes for realizing the program.

These testing instruments can be classified into:

- The ground test equipment for the functional tests
- The test benches for the software
- The ground test laboratories for the environmental tests

The *ground test equipment* for the functional tests allows us to:

- Verify the interfaces and compatibility of the devices during the integration tests
- Verify the functioning of the integrated electrical devices and subsystems
- Determine the margins of function of the devices and subsystems
- Verify the integrity of the devices and subsystems and their function with the flight software
- Configure devices and subsystems for the launch

Generally, the ground test equipment is divided into:

- Specific Check Out Equipment, SCOE, which are test benches for subsystems, feeding, conditioning of the batteries, etc.
- Overall Check Out Equipment, OCOE, which are test benches for telemetry/telecommand, measurement registers, peripheral calculators, control screens

These means use different measurement tools and information instruments several of which are commercially available and others instead which require specific development for the program.

The program team must therefore have a design vision, but with the knowledge of how to use multi-project configurations to maximize efficiency and reliability.

ESA has defined standards of architecture and informatics languages in the past years to make AIT procedures homogeneous for various satellites developed for various applications.

Test benches for software are always more important given the wide-ranging use of software in guidance and control systems of space system.

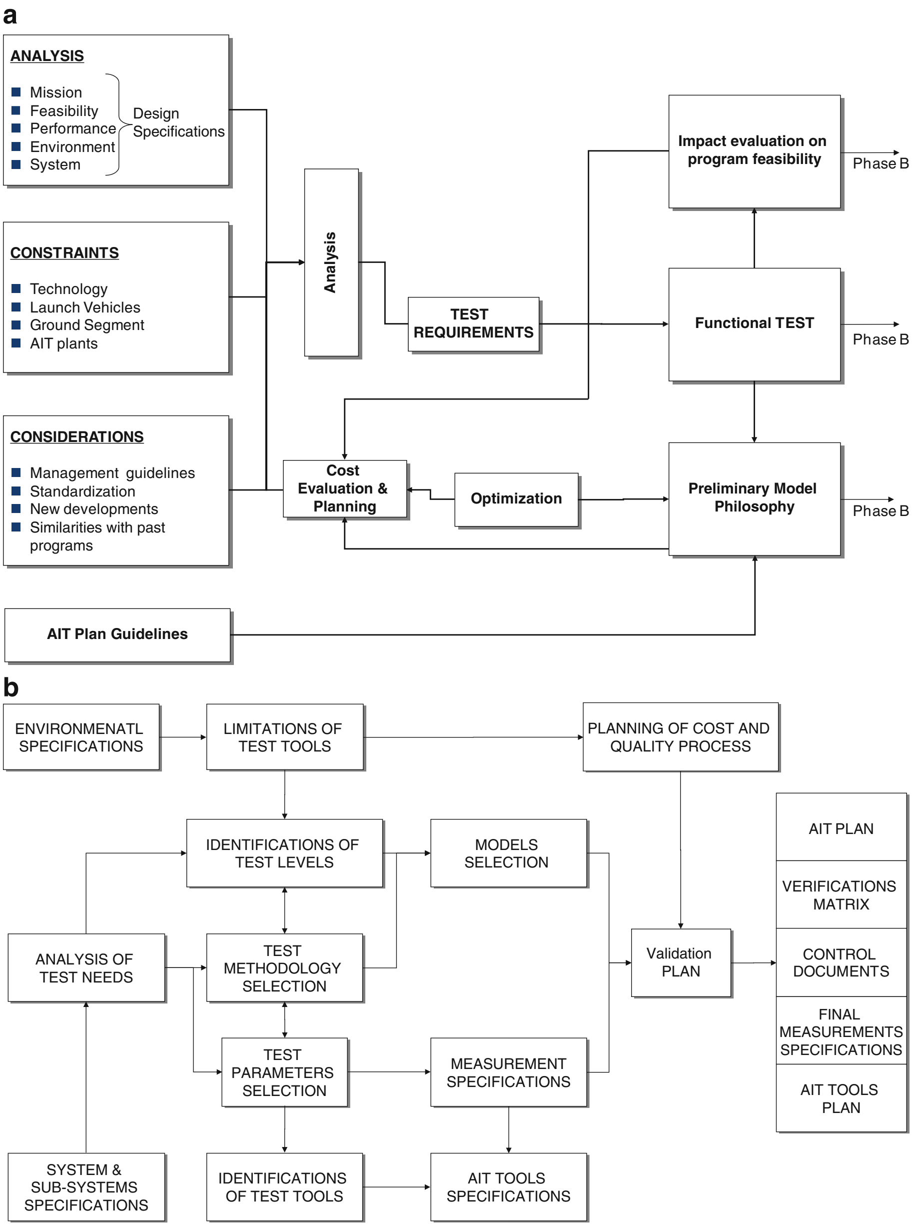


Figure 4.21. Functional chart of the test program logic for (a) Phase A, (b) Phase B, (c) Phase C/D.

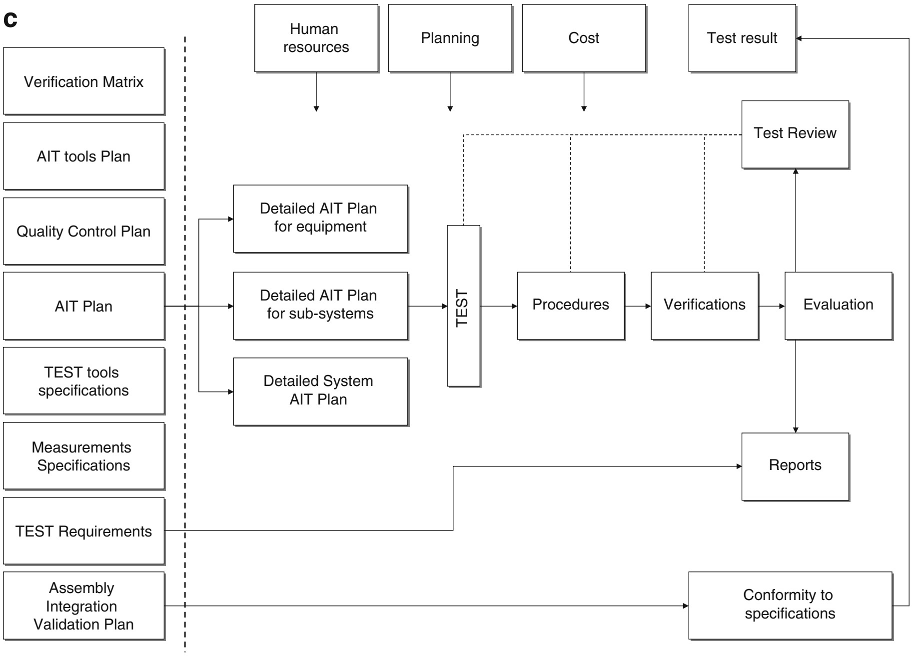


Figure 4.21. (Continued)

In general, it is a good idea that human resources dedicated at the development of flight software are not the same ones that carry out verifications and qualification.

The realization of test benches that can simulate the dynamic behavior of subsystems and the system through analogous calculators on board is almost always specific to each program.

The *ground test laboratories* are environmental tests that are usually made up of three classes according to the tests:

- Mechanical tests: laboratories for testing vibration, acoustical testing, shock testing, and inertia tests
- Thermal tests: laboratories for thermal void and radiation tests
- Electromagnetic tests: anechoic rooms for testing electrostatic or conduction discharges

These laboratories are facilities which are dimensionally important and functionally significant whose realization and maintenance are justified only by technical or economic requirements.

In other words, a Prime Contractor of commercial satellites will find it convenient to develop his own facilities, laboratories for environmental testing at his own expense only if he foresees using them for a broad range of satellites whose testing, paid by the customers, will cover the cost of investment.

In Europe there are two testing centers that can be used even on a temporary rental basis for this purpose.

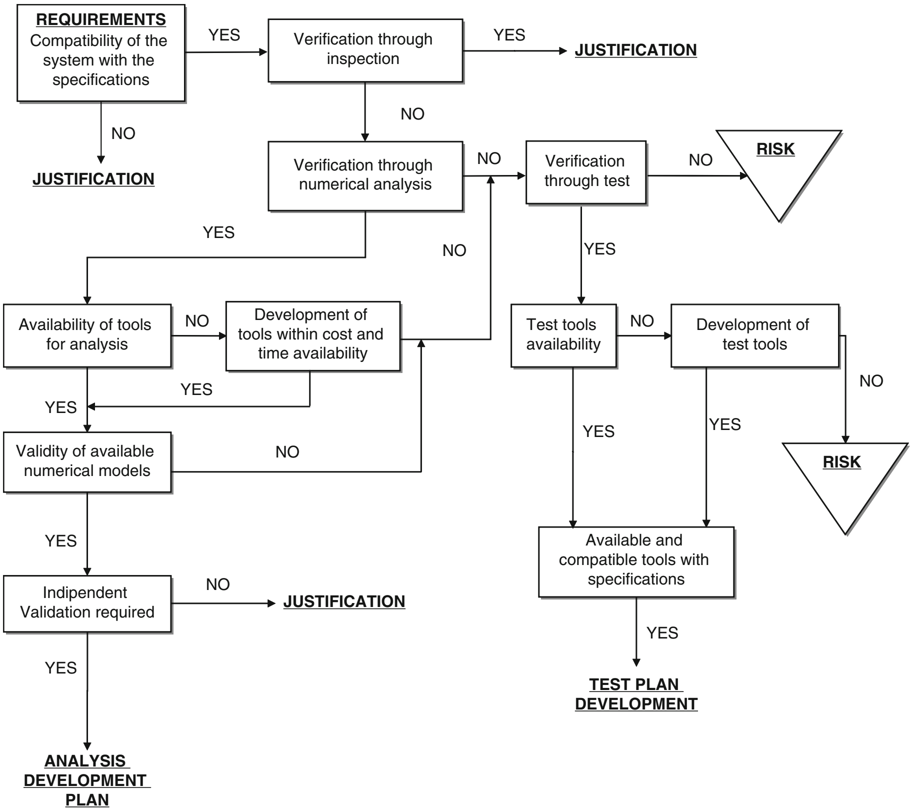


Figure 4.22. Example of functional logic for a decision-making path of an AIT Plan.

There is a large AIT laboratory at ESTEC, ESA's technological center in Holland for large satellites.

The private company Intespace has a test center at Toulouse which Prime Contractors use to conduct environmental testing on their satellites.

Then the various Prime Contractors can also have partial testing centers, preferring to realize several tests in house and others preferring to rent external laboratories.

In the definition of the AIT Plan, therefore, the availability of testing instruments is one of the keys to the decision-making process and development of the program.

Figure 4.22 illustrates an example of the possible decision-making path according to various criteria, cost, and availability of test laboratories.

Obviously, every decision-making path defined in Phase B of a program must have alternative options to follow in Phase C should there be unforeseen circumstances.

Following the decision-making diagram, the first-level test diagram is defined, as shown in Figure 4.23, when the basic philosophy of test is applied to identify maximum number and typology of models (SM as Structural Model, EM as Engineering Model, TM as Thermal Model, RM as Radiofrequency Model, IM as Integrated Model, QM as Qualification Model, PFM as Proto-Flight Model, FM as Flight Model).

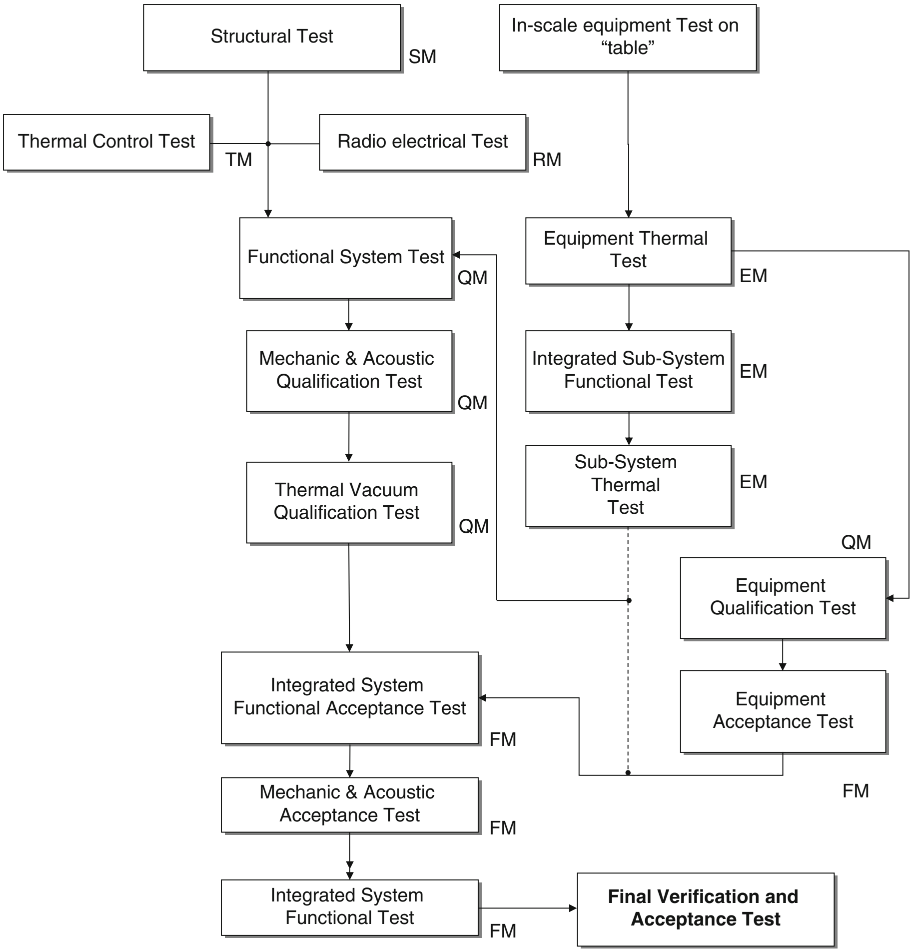


Figure 4.23. Example of main test sequence functional chart.

An approach for testing like the one just described is consequently a starting point for looking for a given program to define a simplified path that can follow the mission specifications.

It is important to point out that in the operational and logistic reality of a space program, whose international implications have already been underscored, the geographical logistic criteria of the testing laboratories is quite influential since moving resources and test benches for testing must be minimized to avoid increase in costs, delays, or risks due to transportation.

The AIT Dimension of a Space Program

The functional and environmental testing must be carried out by specialized resources that can understand the assembly and integration problems and also the overall operation of the system that is being undertaken.

In a program team two or four human resources in addition to the Program Manager can manage the AIT, while at the supplier level and according to the size of the program the resources dedicated to AIT can increase to a dozen dedicated people and this underscores the importance of this delicate process in the life of a space program.

Moreover, this activity is a significant part of the budget for a program, with respect to development cost or the material development cost.

Generally, the AIT takes up 20% and 30% of a space program for special cases such as scientific satellites or habitable systems.

To give an idea, let's consider a high-capacity commercial telecommunication satellite whose total budget can be about 300 million euro, the AIT can take up to 20%, that is about 60 million euro, of which the 20% or 30% which are only environment testing.

Once it is launched into orbit, a space program, due to its nature, can only undergo limited or no modifications to its configuration. For this reason the correct operation of a system essentially depends on the rigorous application of required models of a detailed onground testing plan.

4.5. Planning and Schedule Management

As we have already mentioned, the life of a space program in its realization phase as well as its in-orbit phase is a multi-year project.

In the first phase the timetable can last several years depending on the complexity of the mission.

In general, an application or scientific program that offers major technological innovations can have a realization phase that can be synthesized in Phase A for about 6 months, a Phase B of about 9–12 months, and a Phase C/D with a minimum duration of 3 or 4 years.

It is clear that the length of the timetable of activities is one of the essential objectives of the program team and since these activities are of a human and industrial nature, risks due to delays for unforeseen circumstances or for underestimating the efforts required are rather likely possibilities.

In each program there are, as we have already seen for technical margins, delay margins that are physiological at various levels for the various players of a program.

The problem with delay management is that once one is activated, at each phase of the program, there can be suddenly a chain of subsequent delays that risk getting out of the control of managers with dramatic consequences for the overall program.

In management technique essential tools for the control of program development and the analysis of the impact of delays are GANTT diagrams and the PERT method (Program Evaluation and Review Technical).

However, it is not the objective of this book to provide the details of these two tools that are analyzed in-depth in special books and courses since the conception of these two methods.

However, we would like to cite several general elements that describe the GANTT and PERT methods.

The GANTT diagrams are always present in all management systems because of their clarity that easily provides the reader with the key elements of the activity timetable.

However, such diagrams cannot cover all of the management's requirements in programs with hundreds of Work Packages. This weakness is because their nature is essentially placed on the axis of a mere time calendar and does not express the existing interdependence with various activities.

In truth, the causes of a program's various problems and delays are actually found in these interdependencies.

Therefore, to take into account the criteria of interdependence related to technical complexity, multiple suppliers, and interface in the customer-program-supplier triad, we use PERT methods.

Planning according to the PERT method occurs in two phases:

- Identification of activities, i.e., the analysis of the program broken down in Work Packages with the explanation of the chronological order in which they must be undertaken.
- The construction of a time network that respects the sequence of activities and takes into account the conditions imposed by the program for the management of delays.

The interdependence of Work Packages is done in nodes which in the PERT network are the relative score sheet for the realization of a significant work achievement, to which various related Work Packages have contributed.

For example, in realizing a device we can proceed to integration and partial tests even with the delay of a component, but it will be identified with "the latest date" in which the entire device will undergo a delay in the integration and supply to the program should the component not be available. This delay will affect the subsystem within which the device will be located and finally the entire program will be delayed.

The PERT network is therefore constructed by theorizing several delay times of the component as well as other delivery times by possible suppliers in order to maximize the range of alternatives.

In building the network, the so-called "critical path" is highlighted (the succession of activities which lead to the latest final delivery date), the one for which the time margin is zero and therefore the most critical one.

There can be more than one critical path and there should be more than one. Definitely the determination of the critical path and the margin analysis allow program team to take rapid decisions and to activate the necessary means in time to put the right corrective actions into place.

For example, in the case of the previously mentioned device, as we approach the depletion of the critical path, the program team of a company steps into action to find an alternative solution which could be the purchase of the same component from another program of the company, where the component is not in the critical path.

Planning Organization

Planning is a method responding to the objective for the management of delays.

The program is broken down into activities, Work Packages, in compliance with the technical organization defined for realizing the mission that is detailed in the Management Plan.

The planning, schematically shown in Figure 4.24, has generally undergone two distinct moments, which are its elaboration and development during the course of achieving planned activities.

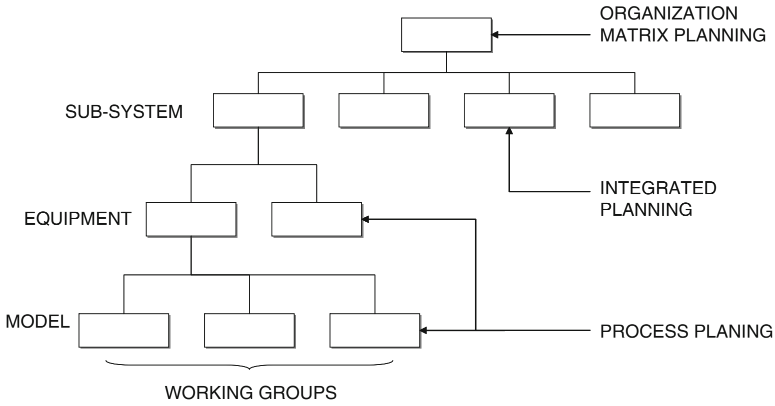


Figure 4.24. Example of planning level for a program.

Planning at the start-up of a program can generally lack several functional elements because several technical data may not be available because of feasibility or definition studies that have not been completed (for example, by subsuppliers).

The first stage of planning is therefore global and summary and will have to stress key moments in realization along with the interventions of the leaders directly involved.

This preliminary planning can therefore facilitate negotiations in progress among program players to define a realistic timetable and to define which activities are necessary to start up immediately because of their critical nature.

At a second stage, a detailed plan is drawn up which gives the logic considered appropriate for realizing the program with conditions and relationships among the players.

Generally, in space programs, Planning is detailed at the subsystem and global planning is done with network methods.

The management of delays therefore requires that time dates accumulated by various activities are in compliance with a homogenous and common timetable among all players. In other words, the timetable of activities must be defined in time and work both in days and weeks, in phases for all suppliers with the program team and finally with the customer to avoid incongruities from various timetable references.

In space programs, almost always within the industrial unit there are the realities of various nationalities and continents and timetable conditions (vacation, holidays, leaves and other things) creating a lack of homogeneity, which should be avoided.

Detailed Planning is a “living” document of a program and the team must update it as realizations occur.

Generally, a first interaction of the PERT method creates a total duration of the program that is greater than what was foreseen in the contract. In truth, PERT is a planning method for subsequent steps that is based on the estimate of subsequent steps compared with foreseen time frames.

Nevertheless, we work on reducing time, restricting the duration of several noncritical activities, reaching a plurality of possible timetables for activities.

Often several goal dates are “desire” and are not really urgent. These objectives can be changed at more appropriate times by increasing security margins as the program develops.

Moreover, activities on devices or subsystems that are on the critical path can be reduced by temporally reallocating them within other technical services instead of centralizing them in only one, or by using other external suppliers.

The disadvantage can be a potential increase in costs; therefore, a combination of measurements must be carefully evaluated by the program team.

Should these measurements not be sufficient, we might think about more drastic measures such as simplifying or suppressing determined activities, verification and testing for example, but generally we tend to avoid this process.

Usually, modifying the timetable and putting critical activities parallel are the most satisfactory solutions.

The organizational responsibility is therefore directly referable within the Program Manager team that delegates a planning manger, the Project Controller, to interface with the customer and suppliers, given the fact that management of delays is carried out from the customer towards the program team and from the program team to suppliers. If there are several levels of suppliers, each hierarchical level will carry out a planning for managing delays.

The Planning document is therefore updated usually on a monthly basis. In any case, in the most critical planning or during the final phase of the program, the update cycle can be weekly.

Control Cycle

Once established, the Planning document and the frequency of updating are performed by a control cycle, through the progress reports on activities.

The objective of the control cycle is to update the program PERT, usually each month, to allow having a detailed idea of the situation and the activities in progress.

PERT stands for *Program Evaluation and Review Technical*, and it is a technique for project management developed in 1958 by Booz, Allen & Hamilton, Inc., an engineering consulting firm, for the Special Projects of the US Navy office with the objective of reducing time and costs for designing and building armed nuclear submarines with Polaris missiles, coordinating several thousand suppliers and sub-suppliers at the same time.

With PERT, project activities are kept under control, using a reticular representation that takes into account the interdependence among all the activities needed for completing the project.

It should be pointed out that the PERT algorithm is not elaborated on a time sequence of activities because it does not take into account the availability of resources, it considers resources to be infinitely available (Figure 4.25).

However, the information from progress reports, at every level, might not include a detailed analysis of the status of activities, but must contain the notion of impact on Planning to allow the Project Controller to integrate the contribution of various suppliers to the overall PERT.

Obviously, the program team must analyze every progress report to monitor the status of activities at the level of information contained to know how to evaluate if a determined report points out or not a potential criticality for the program.

Following the formal acceptance by the program team of an impact modification on PERT, the Project Controller updates the GANTT, which thus becomes the new reference.

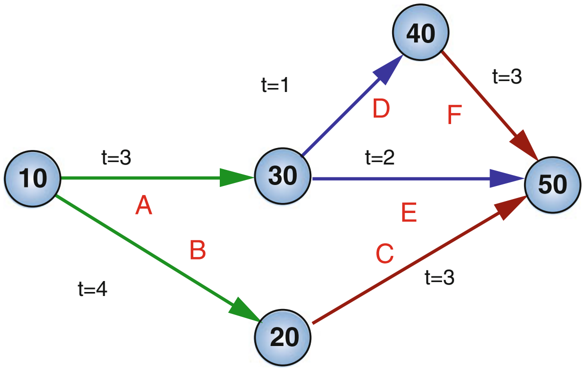


Figure 4.25. Example of a PERT diagram for a 7-month program with 5 milestones (from 10 to 50) and six activities (A, B, C, D, E, and F).

Since space programs contain hundreds of different activities management software has now been developed which allows the constant updating and operation of PERTs and GANTTs.

The GANTT diagram is a support tool for project management. It was called this in memory of the American engineer who studied social sciences and who created it in 1917, Henry Laurence Gantt (1861–1919).

The diagram is made starting with a horizontal axis, representing the time arch of the project, subdivided into incremental phases (for example, days, weeks, months), and by a vertical axis, a representation of the duties or activities that make up the project.

Horizontal bars of variable length represent the sequences, length and time arch of each single activity of the project (all the project activities make up the Work Breakdown Structure).

These bars can overlap during the same time arch and indicate the possibility of several activities being carried out *in parallel*. As the project progresses, the secondary bars, arrows, or colored bars, can be added to the diagram, to indicate the completed subordinate activities or a portion of them completed. A vertical line is used to indicate the reference date.

A GANTT diagram therefore allows us to graphically demonstrate the timetable of an activity, useful for planning, coordinating, and tracing specific activities in a project, giving a clear illustration of the progress of the project represented; on the other hand, one of the aspects not taken into consideration in this type of diagram is the interdependence of the activities, a feature of the reticular planning, the PERT diagram.

In general a series of attributions can be linked to each activity: duration (or date of beginning and end), predecessors, resource, and cost.

The Gantt chart shown in Figure 4.26 illustrates the following desirable features:

- A heading that describes the WBS element, the responsible manager, the date of the baseline used, and the date that status was reported
- A milestone section in the main body (lines 1 and 2)

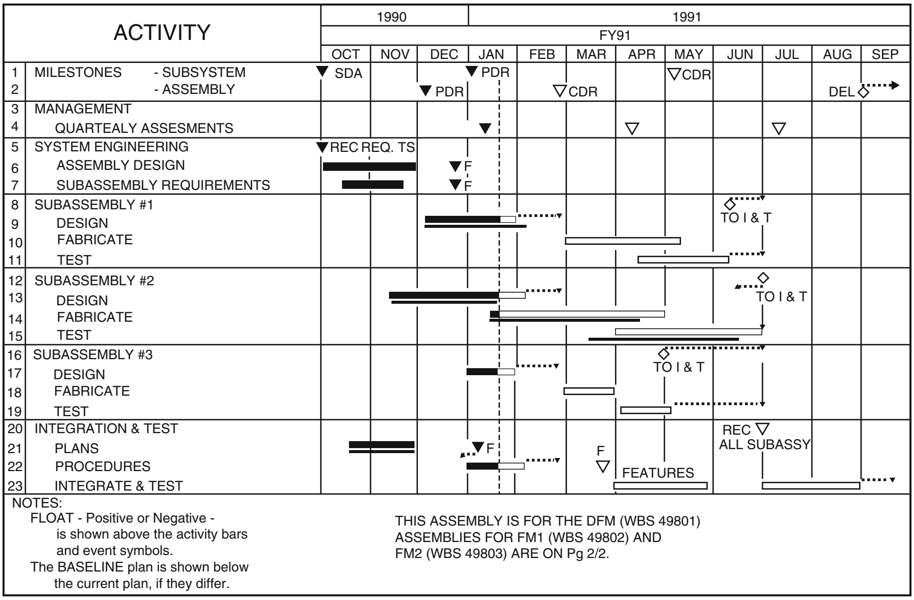


Figure 4.26. Example of a simple Gantt diagram. (source: NASA System Engineering Handbook 1995).

- An activity section in the main body. Activity data shown includes:
  - WBS elements (lines 3, 5, 8, 12, 16, and 20)
  - Activities (indented from WBS elements)
  - Current plan (shown as thick bars)
  - Baseline plan (same as current plan, or if different, represented by thin bars under the thick bars)
  - Status line at the appropriate date
  - Slack for each activity (dashed lines above the current plan bars)
  - Schedule slips from the baseline (dashed lines below the milestone on line 12)
- A note section, where the symbols in the main body can be explained

Moreover, information means also allows us to visualize the so-called “tendency curves” which basically supply the program team, starting with each data of planning for each element, a time frame for an updated time curve which illustrates what the final estimated delivery date of a device, subsystem or system will be with a timetable.

Chapter 5

Risk Management of Space Programs

The risk management of space systems is a process which is expressed through the dual determination of “Reliability and Security” requirements during the program development phase and their control during the operational phase.

Reliability has its origins in aeronautics history, and it is for this reason, ever since its inception, it has been related to security requirements and was transferred to the space sector beginning in the 1950s.

Before the 1940s, the quality aspects of “Reliability and Security” methods and tools, intuited on the basis of designers’ experience, were more of an art than a scientific tool.

In the 1940s, knowledge of the reliability of systems was greatly developed out of the need for designing safe and efficient equipment during war time.

For example, formulae for calculating the reliability in series were developed during studies on the German missile V-1.

In the 1950s, in the USA, reliability also became an important field of study for electronic engineering, whose growing complexity, especially in military armaments, and therefore space missiles became the major cause of frequent breakdowns and failures.

In 1952, the US Defense Department founded the Consulting Committee for Appraisal of Guidelines Research and Evaluation, AGREE, whose research demonstrated that electronic equipment was so unreliable and difficult to maintain that if a component was worth 1 dollar, the cost to maintain it in operation was 2 dollars a year.

Therefore, their intrinsic project had to contain the foundations of “Reliability and Security.”

The conclusions of the AGREE report were published as American military standard, and were then adopted by NASA and high-technology aerospace industries.

In the 1960s, many new tools for Reliability and Security were developed, especially for the aeronautics, space, and nuclear industries.

In 1961, Bell Telephone Laboratories introduced the concept of the “fault tree analysis” as a method for evaluating the security of a system designed to control the launch of the Minuteman missile.

Afterwards, Boeing used the concept again and invented a way of building the fault tree as a “method of analysis for breakdown and effects modalities” and this method has been used in aeronautics and space programs regularly since that time.

M. Spagnulo et al., *Space Program Management: Methods and Tools*,
Space Technology Library 28, DOI 10.1007/978-1-4614-3755-0_5,

The design phase was no longer part of the *production cycle*, but rather synthesized every reliability aspect of the entire system, both at the beginning—during the construction/phase phase (quality and security of machines, organization, product)—as well as during the utilization phase at the end to avoid any type of decline in the quality and therefore the security of aeronautics programs or breakdowns in space programs.

In the 1970s, ergonomics studies, which had already been ongoing for 20 years, marked a further turning point in the evaluation of human error, introducing new aspects of the “Reliability and Security” problem, emphasizing the relational conception of activities.

Since human and technical errors are usually related, they both became the results of the system’s malfunctioning.

The various parts had to be observed in their totality as a single system in which not just the single elements were important, but also their relationships, the “interrelations” between man and machine, the so-called MMI “Man–machine Interfaces.”

This new method thus introduced new requirements of “Reliability and Security,” which can be managed by a Program Manager, who can adopt in time the revision and design tools of reliability theory, such as:

- Foreseeing the probability that the system will become unreliable and verifying the impact of an event on security
- Foreseeing the probability of restoring reliability

The first case involves knowledge which gives the reliability degree of the process; the second case is a decision-making operation which provides preventive actions aimed at increasing reliability.

It was therefore understood that to reach adequate levels of “Reliability and Security” in industrial development, it was necessary to manage the risks of the organization. This established the basis for the creation of Risk Management, a method which guaranteed the preventive analysis of risks, their evaluation, and their control in the future.

The considered risk refers to a potential loss, linked to an unfavorable event; the management aspects and the management staff concern the hypothetical relationship between risk and possible loss.

The aim of Risk Management is therefore to reduce a possible loss through strategies and methods which minimize risk.

Risk Management can also be defined as all the processes planned in the beginning and aimed at reducing the probability of a loss to the greatest degree possible.

5.1. The Concept of Risk

In Risk Management theory, the risk relative to a negative event for a program is defined by two parameters:

- The probability of the event occurring
- The seriousness of the consequences of the event

Likewise, risk can also be defined by:

- A parameter belonging to the past that contains all the negative events called "the causes."
- A parameter belonging to the future that contains all the potentially observable events in the future called "the consequences."

Irrespective of probability, risk can be classified into four categories:

- Catastrophic risk, corresponding to consequences such as the loss of human lives (explosion of the Space Shuttle Challenger in 1986 or the Shuttle Columbia in 2003), or the total destruction of the system (in-orbit failure of a satellite), or also the partial destruction of the surrounding environment (explosion at takeoff of the Long March launcher in 1996 with effects on the surrounding geographical area)
- Critical risk, corresponding to the effects, such as serious but not permanent injuries or limited environmental damage
- Significant risk, corresponding to effects such as light injuries or the stoppage of a mission without loss of the system
- Minor risk, corresponding to problems in system elements that do not have an effect on the success of the mission

Acceptable Risk

We define acceptable risk as the risk that is considered tolerable. It is the result of a decision-making process following objective analyses and comparison with other similar and known risks and defines a range of natural, social, technological, and financial effects that can be born by the system.

Obviously, acceptable risk is never defined or approved by the Program Manager, but is the result of a higher level decision.

For example, in the case of space launches from the French base at Kourou, an acceptable risk level has been defined for years, which involves the effects related to destruction in flight or malfunction and fall back to Earth of the Ariane launcher during the course of a mission.

Obviously, in calculating this acceptable risk, human mortality on ground caused by the vehicle's crash has not been ever taken into consideration as a principle. All possible "Reliability and Security" parameters have been taken into account. However, it is not possible to completely rule out a catastrophic event. This is why the major competent authority, the French government, takes the responsibility of possible catastrophic events and becomes in some measure the guarantor of definite acceptable risk.

Figure 5.1 illustrates an example of how to calculate the value of acceptable risk. It can be seen as a compromise between how much the responsible agency is willing to pay at the beginning of the event and at the end of the event, in financial terms, media and public image impact, and other things.

It is helpful to also use a criticality graph in Risk Management.

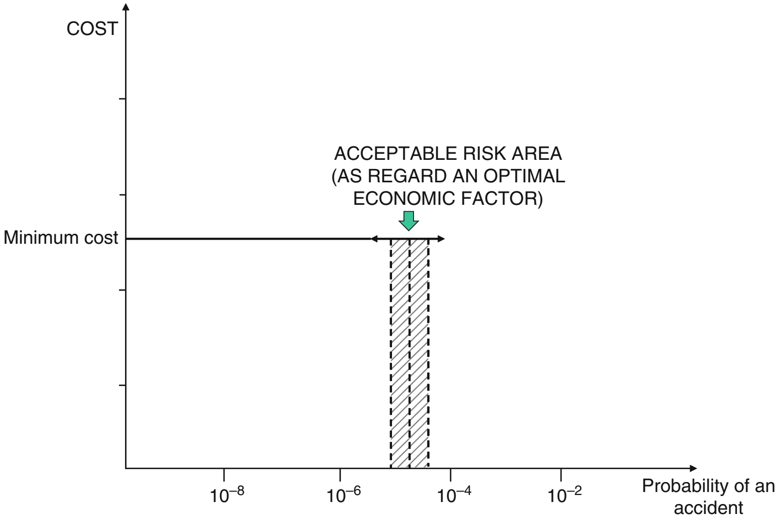


Figure 5.1. General analysis of risk.

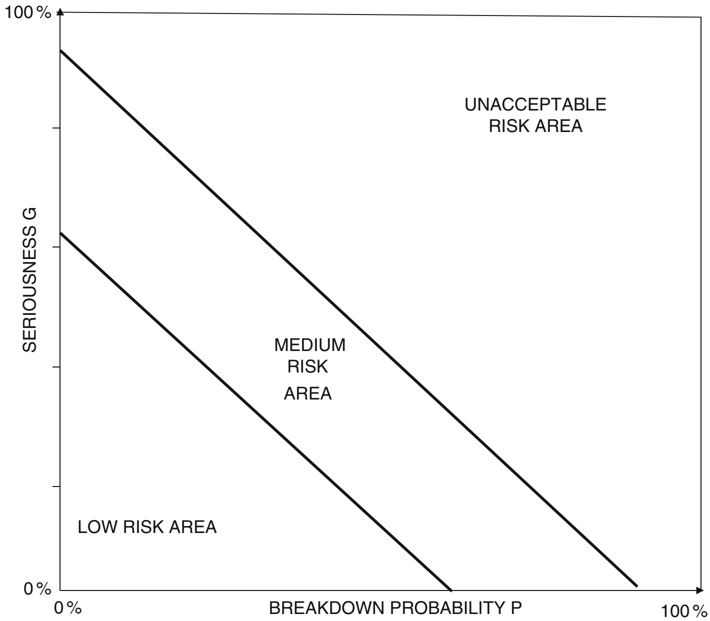


Figure 5.2. General risk/effect analysis. (Farmer criticality graph).

The so-called Farmer graph, schematically illustrated in Figure 5.2, presents the probability of an event on the x-axis and the evaluation of the seriousness of its effects on the y-axis. It gives us an immediate evaluation of the range of risks.

In order to determine the function F such that, $P = F(G)$, if g_0 is the value corresponding to a seriousness event equal to zero, P is the probability and G is the seriousness, we can write

$$F(g_0) = 1.$$

Since F is not a null function in the interval $(g_0 - \infty)$, we obtain $\int_{g_0}^{\infty} F(t)dt > 1$.

It follows that function F is the probability density.

The Passage from Unacceptable to Acceptable Risk

Three methods allow the passage from the domain of unacceptable risk to the domain of acceptable risk.

Forecasting Method

In this method, we tend to decrease the probability P that a negative occurs maintaining the seriousness G of the effects unchanged.

As illustrated in Figure 5.3, the passage from one domain to another is done in parallel to the probability axis.

Protection Method

In this method, we tend to decrease the seriousness G of the effects of a negative event, maintaining the probability P unchanged.

As illustrated in Figure 5.4, the passage from one domain to another is done parallel to the seriousness axis.

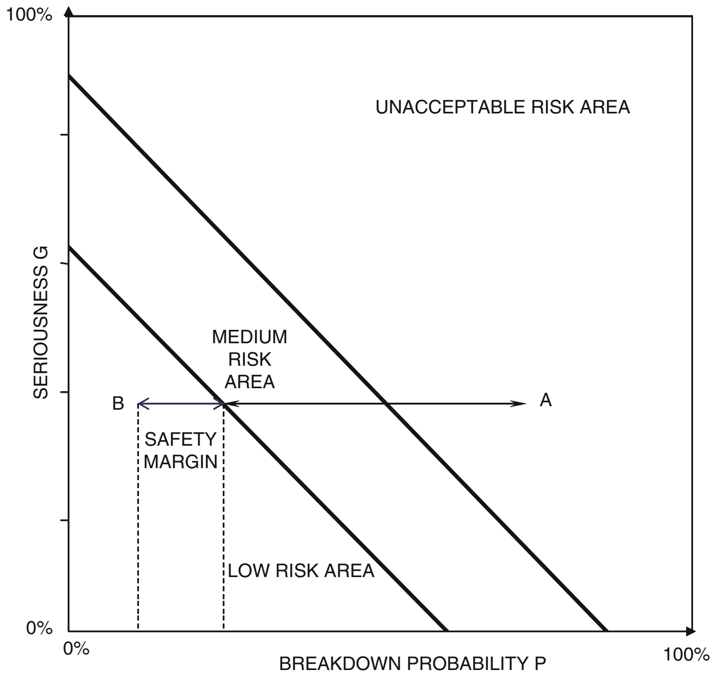


Figure 5.3. General analysis of risk prevention.

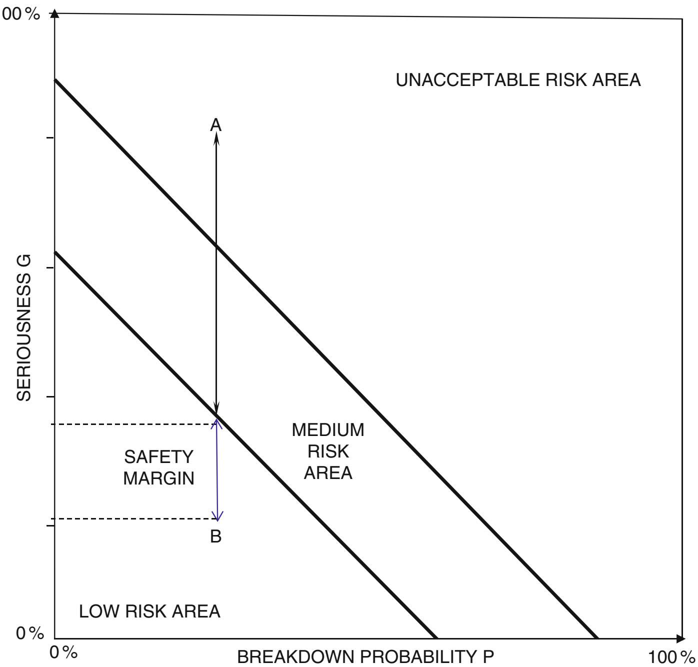


Figure 5.4. General analysis of risk protection.

Insurance Method

In this method we tend to bring the seriousness *G* negative effects of an event to a third party.

As illustrated in Figure 5.5, the method consists in having the entire function risk shift behind point A, which is considered acceptable. Obviously the greater the security margin, the higher the insurance, technical and financial costs.

5.2. Technical "Reliability and Security" of Space Systems

A space mission is defined as:

- Successful, if all predetermined objectives, specifications, have been achieved
- Deteriorated, if a part of the objectives have been reached, whether or not there have been Security problems
- Failed, if none of the objectives have been reached, whether or not there have been Security problems

The success of a mission globally integrates with all the objectives of "Reliability and Security" can be defined as:

- "Reliability," that is, the nominal realization of all the functions which combined towards reaching the objectives. The optimal completion of this process is achieved when all the human means and materials put into place by the program

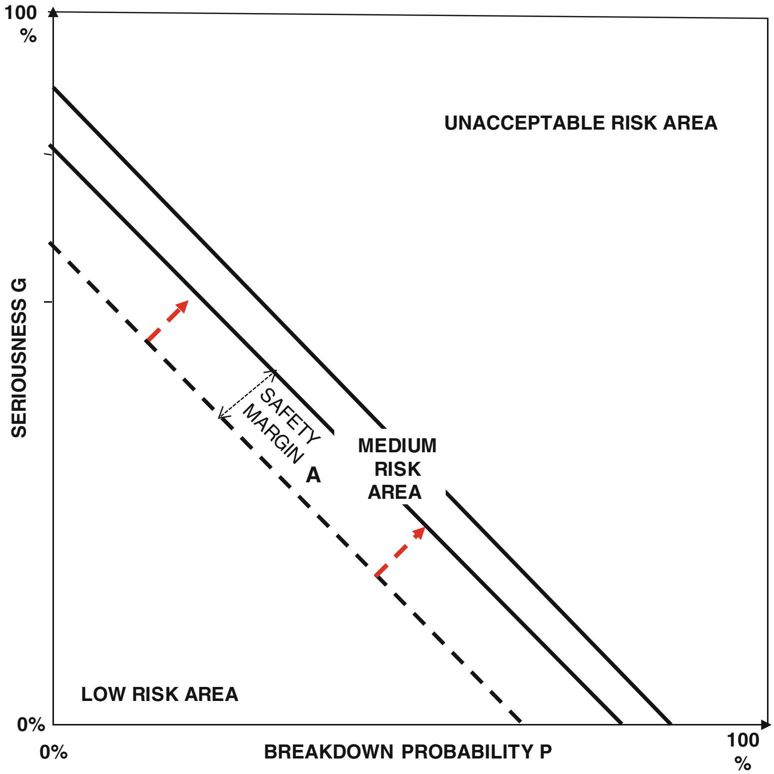


Figure 5.5. General analysis of risk insurance.

guarantee from their conception the Reliability levels compatible with the technical success of the mission. In other words, the process is the technological and operation effort to be enacted.
- "Security," the nominal realization with regards to the requirements which combined for the total or partial reutilization of the human means and materials enacted by the program.

"Reliability" in the traditional sense of the term therefore combines with both the technical success of the mission and with the maintenance of an adequate Security level.

Risk Management for "Reliability" therefore follows the analysis of the quality management of the means, in order to allow reaching the objectives whatever the complexity level of the mission may be.

Risk Management for "Security" refers then to the analysis of the accidental events which can examine the availability in retrospect, broadly speaking that is, of the means enacted by the program for the mission.

Naturally, Risk Management also refers to the impact of the mission on the surrounding environment and the reciprocal effects of the environment on the system.

The quantitative objective of Risk Management is directly correlated with the importance given to the resource and possible loss associated with it; therefore, the

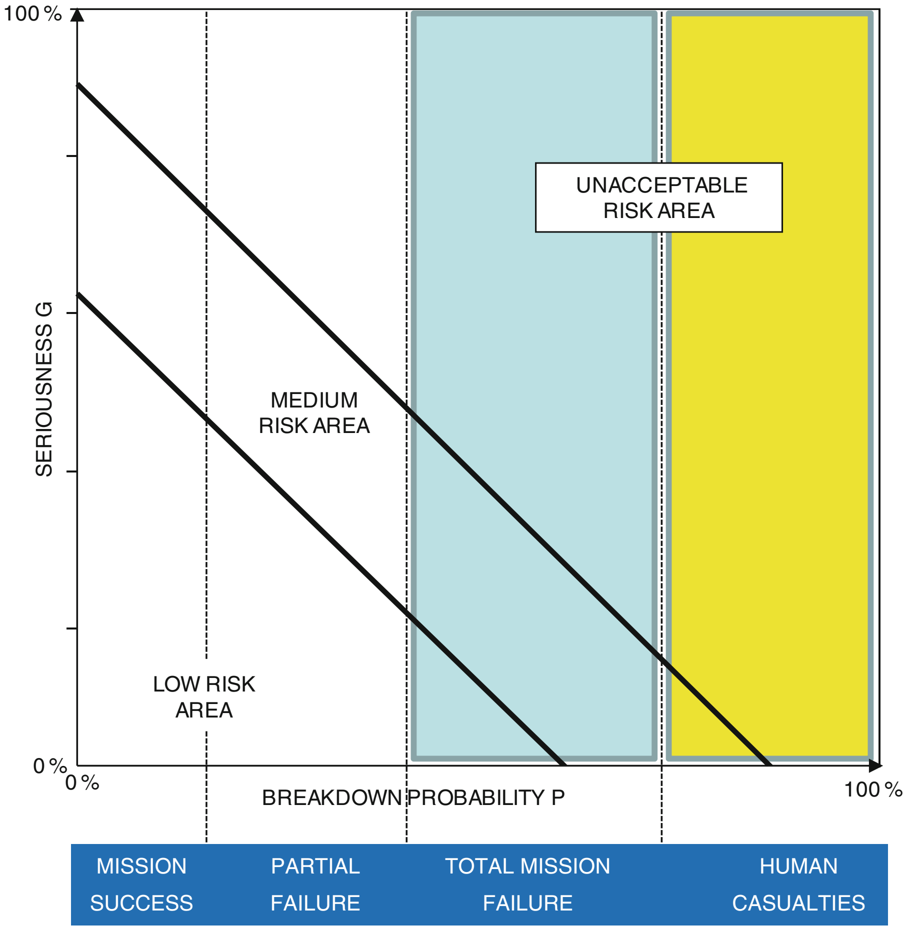


Figure 5.6. Relationship of success/criticality.

"Security" must cover the integrality of various mission aspects, as it is successful or not.

Figure 5.6 provides a visualization of the relationship between technical success, "Security," and its relative relationship with the criticality chart.

Product Assurance as a Reliability Tool

The selection of an appropriate quality standard in the realization of a space program involves the design and manufacture of each single element of the system with quality and reliability criteria.

It involves one of the main objectives for realizing the mission, respecting functional requirements, tolerating environmental loads, and corresponding to operational expectations.

Quality standards can be different according to the mission type; it appears evident that human space missions present extremely high quality requirements and with high levels of redundancy, with respect to a robotic mission (such as a telecommunication satellite or an inhabitable spacecraft cargo).

The monitoring of the life cycle of a program's products, whether they are basic components or equipment or subsystems, is an activity defined by contract and performed at specific milestones related to program reviews.

For this reason, from the offer phase, the Management Plan will have to include a "Product Assurance Plan," P.A. Plan, the flow of activities planned to verify the cycle of the project's life, the production cycle, and the integration cycle of each single component of the space system to be realized.

The objective of "Product Assurance" is therefore the guarantee of Quality control, which starting from customer requirements manages to follow the entire life cycle of the product: design, development, manufacture, qualification, integration, and acceptance.

The P.A. Plan drawn up by the Prime Contractor and accepted by the customer is applied in sequence to the subsuppliers for each product for which they are responsible.

Within the program team, the Quality Assurance Manager will be charged with verifying the enactment of an industrial policy for the product's Quality.

The "Product Assurance" activities usually begin with Phase B and continue in Phases C/D, while specific activities can be enacted in Phase E; usually they are affected in accordance with internal quality procedures and specifications of each industrial organization and must be in compliance with ISO 9100 standards.

The P.A. Plan is therefore a binding contract document and constitutes the instrument of the interactive process of risk management.

5.3. Financial "Reliability and Security" of Space Systems

As we have already pointed out, Risk Management is defined as all the processes, planned for time, aimed at reducing the probability of a loss, including a financial one, to the greatest degree possible.

The realization of a space program requires significant investments in the feasibility study up to the construction to launch and use in orbit.

Starting from the moment in which these investments are engaged for the realization of the mission, i.e., they are completely, partially or in any case allocated, they are financially under a set of risks which can have a negative or sometimes positive impact.

These risks can be:

- Personal, meaning the inability, for example, of the organization assigned by management of the mission to generate profit and cover the investment.
- Economic, commercial, or technological, meaning, for example, a fluctuation in demand for a satellite service because of a decrease in the overall economic activity of a nation or a continent, or a technological development which brings about a new discovery which can supply the same service at a lesser cost. In the last case, there is the outstanding story of the commercial programs Iridium and Globalstar

which in the 1990s were developed with the launch in orbit of dozens of satellites into LEO, "Low Earth Orbit" to provide mobile telephone services on a world scale. Despite the investment of billions of dollars and excellent technological results, the missions failed their commercial objectives because of the effect of diffusion and less expensive GSM telephone systems.
- Variable, which means for example, an accident during the launch phase or the malfunction of a device or subsystem during the orbital life cycle with an impact on the mission.

Obviously, the first two types of risk cannot, with the exception of extraordinary situations, be predicted and therefore preventatively managed, while variable-type risks can be predicted.

For example, the failure of a launcher to launch a satellite successfully can be predicted as a variable event.

In this case, Risk Management attempts to neutralize the effects of determined types of variable risks, transferring all or part to compensation, called a premium, which is conferred to a specialized financial agent, the insurer.

In synthesis, in a space program, mainly a commercial one but always more frequently even in government programs, financial Risk Management is enacted with insurance instruments which translate economic losses, on investments effected, which result from variable negative events, into economic sums called contracted premiums in anticipation, therefore negotiated and stipulated with an economic program investment.

Insurable Elements per Program Phases and Type of Risk

Insurable elements in a space program are obviously part of the ground segment (buildings, facilities, staff) and the space segment (launcher and satellite).

Concerning the ground segment, the insurance techniques to be enacted are those related to the normal management of more or less complex industrial facilities, while the space segment has special features which are unique to the sector based on the impossibility of modifying and repairing possible significant damage once the satellite has been launched.

If we consider as an example the case of a program related to a commercial mission for a telecommunication satellite, the elements to be ensured are:

- The satellite, in its various components of pre- and post-launch operations and during its exploitation phase
- Launch service

Therefore, the financial risk phases to be managed for the satellite are three:

Pre-Launch Phase

This phase begins with the signing of the realization contract and covers integration activities, testing and transportation of the satellite; it also covers activities related to the launch campaign at the chosen base. In this phase Risk Management must foresee losses or damage, which results from external causes (shocks, collisions, introduction of external bodies, fires, and explosions) of an accidental or human nature.

Launch Phase

This phase generally begins when the engines of the launch vehicle start burning propellant on the ramp and ends when the satellite is physically released into orbit, separating from the upper stage of the launcher. In this phase, Risk Management must foresee:

- The total loss of the satellite following the destruction of the launcher in flight or if the launcher does succeed in releasing the satellite into the foreseen orbit.
- The partial loss of the satellite following, for example, the incorrect insertion into orbit of the launcher. In this case, the satellite will have to get back into the final orbit consuming more internal propellant than expected and therefore will have less fuel for correcting orbital drift during its operational life.

Exploitation Phase or in Orbit Operational Life

This phase generally begins at the end of the preceding phase; it therefore includes the operations called LEOP, Low Earth Orbit Operations, for reaching the final orbit in nominal position, and ends when the satellite exhausts its own operational life.

In this phase, Risk Management must foresee:

- The total loss of the satellite following an accidental event, or less, such as the breakdown of a critical subsystem.
- The partial loss of the satellite following, for example, the malfunction of a device or subsystem in such a way as to allow reduced supply, in time and quantity, of the foreseen service.

There also are not in these cases stringent or standardized rules, and each insurance policy is more or less negotiated on the basis of the economic availability of the program and the financial capacity of the insurer.

For example, the risks related to orbital life can be covered only for a part of the same orbital life, for example, the first 24 or 36 months, or can cover only partial invalidating loss of the satellite for 50–70% (which means only 50% or 70% of the transmitting capability of the satellite if it is incapacitated.

Even the causes of invalidating risks are the subject of careful negotiation, for example, insurance agreements do not always foresee the premiums for partial or total losses as a result of ascertained defects of design or manufacture, or an inaccurate commissioning.

The Insurance Market of Risks in Space Programs

Given the special nature of the space sector, the insurance market remains fragile and extremely volatile in financial terms. A space program can therefore call upon more than one insurance agency to divide the risks according to the financial ability of each of them.

The market demand is defined as the total sums which in 1 year one or more customers would want to insure simultaneously for the same type of risk. This demand is also defined as Maximum Possible Loss, MPL.

For example, concerning launch services, the annual demand of the market is given from the sum of the MPLs related to all the launch contracts stipulated in the world in that year.

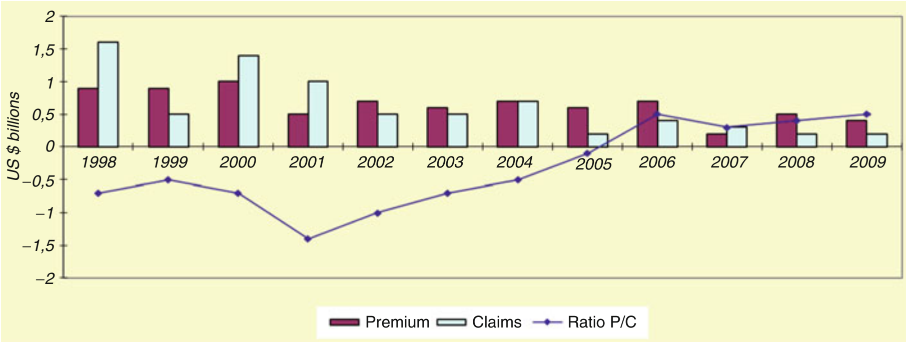


Figure 5.7. Main indicators of the space insurance market. (Air&Cosmos 2209 March 2010 source).

Market offer is instead the total sums which all insurers can put on the market in view of the MPL defined above. In this case the offer is also defined as the market capacity.

If we observe Figure 5.7 which illustrates the period of 1998–2009 of declared losses, the premiums paid and the relationship between premiums on losses, we can make significant conclusions.

The development of the premiums demonstrates the frequent presence of accidents or losses of space systems. In the period considered, about 40% of the premiums were attributable to malfunctions of the launchers and about 60% to the malfunction of satellites.

Since the number of satellites insured has remained numerically stable each year, about 20, the decrease in premiums is mainly due to the fact satellites with low technological innovation have been ordered with launchers which are highly competitive among themselves, and therefore at low cost.

At the end of the 2000s, the market seems to have entered a recovery phase where the number of satellites requested is larger and more costly; therefore, the price of launchers and insurance premiums has begun to grow again.

An important aspect of the market is the premium rate which depends on the number of losses obviously but also from the risk linked to technological innovation of the space systems or also the geo-economic association of the operators. At present, premium rates have gone from 15% and 20% in 2007 to 11.5% in 2009, according to the various suppliers of satellites or launch services.

Another example is the following case of definition according to the “Burning Cost” method of the premium rate related to launch service.

The method begins by the observation, on the one hand, of the annual MPL and, on the other hand, the amount of losses actually paid in that year, always related to just the launch service.

If 15 launches were insured on the market at variable amounts, for example, 3 launches for a value of 80 million dollars each, 7 launches for a value of 60 million dollars each, and 5 launches for a value of 90 million dollars each, the resulting MPL is 1.11 billion dollars.

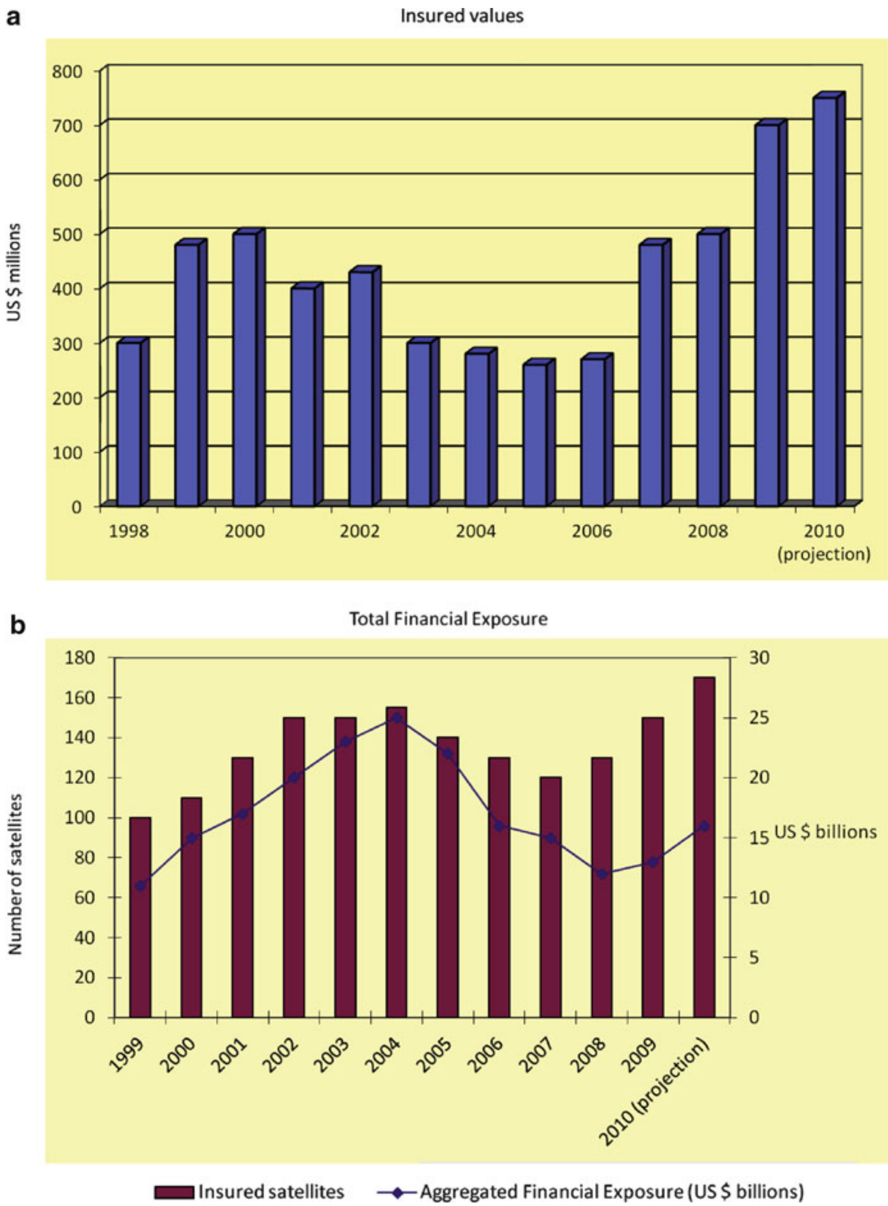


Figure 5.8. Main indicators of the space insurance market trend. (Space News 8 March 2010 source).

If during the year on 15 insurance launches there were 2 registered losses, one related to a premium of 60 million dollars and the other 90 million dollars, the premium paid by the insurance market would be 150 million dollars.

The total Burning Cost will therefore have been (150/1,110) × 100 = about 13%.

If we assume that the insurer has general expenses equal to 10% of the business volume it manages, and that on this business volume its objective is to get a 2.5%

financial profit, i.e. margin, the new insurance rate to propose for the new year will be increased by a value corresponding to the new volume of business given by the 1.11 billion dollars less 12.5%.

Applying the preceding formula we will therefore get [150/(1,110–12.5%)] × 100 = 15.4%. as the new rate to apply.

Figure 5.8 represents two different ways to observe the evolution of the insurance market in the last 10 years.

At the top of the graph is the maximum amount of insurance coverage available annually for a single launch of a satellite. The increase in the last years is essentially due to an increase in the reliability of systems.

The bottom of the graph instead illustrates the total number of satellites insured in orbit compared to the total financial flow of the corresponding insurance coverage.

We can deduce that in the last few years, despite several failures, in general satellites and launchers have performed well to the point that subscribers have produced new insurance capabilities on the market to moderate the premium market.

Chapter 6

Cost Management in Space Programs

6.1. Basic Elements for Economic Evaluations of Space Programs

When a young person expresses the desire to have a career as an engineer, which type of work does he or she have in mind?

Most probably, he or she is attracted by the idea of building complex machines, systems which carry out fascinating operations, the heirs to the machines which were created during the industrial revolution at the end of the nineteenth century and which have continued to evolve.

To date, man has continued to build complex machines for a variety of operations which have contributed to revolutionizing our way of living, travelling, and working.

However, in order to realize these systems, there have been two indispensable requirements since the nineteenth century:

1. Having, and knowing how to use, the technical competences and necessary materials for designing and realizing "the machine."
2. Having the economic resources to support these activities.

Until a few years ago, the engineer's basic training was almost exclusively focused on the first point, design and realization, but this became a major error with the passage of time, since the second requirement is never free from the first one.

You can have various "designs" of a machine, each one requiring very different economic resources in terms of quantity, time, modalities of distribution, and associated risks to its successful achievement.

This means that cost management is an activity that must be carried out before and during a program and it is not merely limited to control in order not to "run over" the defined budget, but it is also a major activity which goes hand in hand with technical planning.

In this chapter we will deal with the conceptual tools to manage problems of an economic nature which greatly influence the planning and management of a program in the space sector.

The analyses of the economic effects associated with a particular program are important in as much as they constitute the essential elements to being able to respond to the following main questions: Does the profit/benefit obtained with the program justify the investment required? What is, among the various technical alternatives put

M. Spagnulo et al., *Space Program Management: Methods and Tools*,
Space Technology Library 28, DOI 10.1007/978-1-4614-3755-0_6,

into place for the program, the best one compared to the specific characteristics of the financing institution?

In order to take the best accurate decision, the so-called "informed decision," concerning whether or not to implement a particular initiative in a specific social-economical context, the analysis of the response to these questions is essential.

This need is, in general, rather evident, but to make it more understandable we can cite a few examples of situations in the past in which these economic considerations were not as decisive:

- 1950: The USSR enacted the decisive impulse to the human space flight program to send the first man into orbit around the Earth in 1961 and to establish Soviet dominion over missile technology.
- 1961: The President of the USA, John F. Kennedy, announced the Apollo program to the world to have an American land on the moon within a decade, in order to demonstrate its ability to recover the technological gap with the USSR.
- The 1970s: the USSR activated programs to increase the power of its military ballistic missiles, to be able to maintain the level of military deterrence with respect to Western armaments.
- The beginning of the 2000s: China decided its human space activity plan, to establish its entrance among the great world powers and high-level capabilities and technological independence.

In the above-mentioned cases, it is the existence of an objective of the highest strategic value which makes evaluations of an economic nature secondary.

In particular, in democratic countries, where high public funding is subject to evaluations of appropriateness by public opinion, high-cost space programs can be undertaken only if: a technical-economic analysis shows a "return on investment" in terms of certain time terms; this is the practice in a "normal" case, or if the objective of the space program has a strategic and political value, which is so important that it is shared as a priority by electors; this is the practice in a "special" case.

If we had to imagine a future example of this latter type of program, we could assume the realization of a space project to destroy or diverge a celestial body which is on a collision course with our planet.

In any case, in the space sector, the importance of economic evaluations related to the project is of fundamental importance.

This is related to the fact that the space sector requires public investments of huge scope and with long-term returns on investment.

In addition, return on investment is often difficult to quantify in a definite way, even if this would be indispensable to be able to deal with the major or minor attractiveness compared to alternative uses of public resources.

A common and sensible question, both by citizens and by political decision-makers is, for example: *"….at this moment for our community is it better to have more hospitals on Earth, or to launch satellites for certain applications?"*

It is wrong to consider that economic evaluations are only useful for supporting high-level political and strategic decisions because even at the technical design level we can "produce" a design with "informed" decisions.

Figures 6.1 and 6.2 show the synthesis of the various utilization levels of economic evaluations.

Level	Responsibility	Criteria for the use of technical-economic analyses
Minimum 6	Level: technical analyst (of equipment or subset)	The designer of any type of equipment for space use usually has an established target for its cost as an input. Even though he might not have received it, he will in any case identify various technical options for the required equipment. The suitable analysis of these options (called trade-off analysis) must necessarily take into account economic evaluations. A pro-active stance in this sense leads the designer to choose a technical option through an economic analysis of the elements which are disadvantageous in terms of costs, and to wonder whether they can be eliminated or reduced by using the technical parameters at his disposal. This continuous loop between technical requirements and the minimization of their impact on costs is at the core of the Design-To-Cost method. This is now an indispensable discipline in the field of commercial-type space activities (i.e., where there is competition).
5	Level: Program Technical Manager	The technical manager of a complex program is always bound by the relative cost of the product. His specific responsibility is to “balance” the “design-to-cost” effort (see Level 6) on single pieces of equipment to channel it into directions which generate greater economic effect and to avoid unnecessary risks instead, where economic benefit would be insignificant. His role is essential in the case a significant reduction of cost could be introduced on a device, only on the condition that a certain feature could be added to another device (i.e., where a modification of the requirements of other system elements is required). In this case a complex analysis of the advantages and disadvantages of both technical as well as economic aspects, from the change option in question, is necessary to evaluate its attractiveness, generally at level 4.

Figure 6.1. Utilization criteria of the economic data program.

6.2. Definitions and Criteria

Recurring and Nonrecurring Costs

The main distinction regarding costs concerns recurring costs, called RC and nonrecurring costs called NRC.

The RCs are costs linked to the supply of a single element, and are costs which recur each time the supply of that single element is required. They depend on the size of the supply batch and are mainly made up of the following components:

- Material cost
- Semifinished products

4	Level: Program Manager	The Program Manager works with the Technical Manager to carry out trade-off analyses of the various available options, in particular regarding the analysis of economic impact. This collaboration is essential even with regards as to how to compare correctly the technical risks and economic benefits identified at level 5. The comparison does not have to be qualitative. Instead he is based on a specific algorithm which translates technical risk and its probability into an equivalent costs (see as follows). In addition, by managing contract measures, is it the only one that can highlight particular financial, technical or operation conditions which allow a reduction of program costs. In this case, these aspects are the object of further trade-off analyses to be carried out with the Technical Manager.
3	CEO (Chief Executive Officer) Industrial level	Many of the typical decisions at the CEO level such as: a) which bids to participate in and at what price b) steering resources to research activities c) which roles to try to cover and how, in national and international markets are based on a technical-economic analysis
2	National (government) level	At the national level the use of economic evaluations is the basis for establishing public funding priorities. In addition, these evaluations are essential for identifying which of the sectors/activities of national interest can present a return on investment in proportion and in reasonable time frame for private industries and which ones are not. This is aimed at focusing public intervention on the latter stage (i.e., where return on investment is uncertain, or too distant in time).
1	Continent level (i.e., the EU…)	At the continent level, economic evaluations are the basis for defining funding priorities, to define development lines considered strategic and to elaborate the multi-year plans of implementation, which are based on the forecasting of the resources put at the disposal of member states.
0	World level (UN, NATO…)	Similar considerations as those for the continental level apply here.

Figure 6.2. Utilization criteria of the economic data program. (Cont.)

Cost of manufacture and control process, acceptance testing cost
Delivery, transportation, and insurance cost

The NRC are instead those costs related to all project, development, and qualification activities to which the element (or item) must be subject before being able to define it as "suitable" to the particular application in the space mission.

It follows that nonrecurring costs are supported only one time (at the beginning, before the supply of the items) and are independent from quantity (recurring) of supply for a subsequent request. In many space sector applications, characterized by

high design complexity and low supply quantities, nonrecurring costs are particularly important to be able to evaluate globally the degree of "attraction" of an initiative.

In certain contexts, nonrecurring cost is the object of dedicated financing, released for strategic reasons by the financing institution (often public).

If this dedicated financing is not available, the sustainability of the nonrecurring costs is committed to the accumulation of existing margins between the recurring price and the recurring cost, during the commercial phase (see the "Business Plan" section which follows).

Costs and Prices

The Cost is the amount of resources the producer of an object needs to complete the supply. The Price is the economic value of the object sold.

In general, the price is equal to the cost increased by the profit margin developed by the producer of the object.

Where it is not explicitly specified in the test, we will always use the term cost (instead of the more appropriate term price) as if each object were considered from the viewpoint of the final purchaser.

Unit of Measure for Costs

Even in the space sector, there is the problem of how to keep account of the exchange rates among the various currencies, of the difference between work cost in various geographical areas, and also of inflation phenomena.

A brilliant solution is suggested in Fig. 6.3 where all costs are expressed in "Man-Year" MYr. The cost of one man year equals a certain number of dollars in the USA and a certain number of euros in Europe.

All of this of course changes with time and Fig. 6.3 is an extract of the one introduced in [1] and which is usually used. This resolves the problem of currency, geographical area of origin and, partially, the inflation problem.

Qualification and Acceptance

Another fundamental distinction to be able to evaluate correctly costs is that between testing (or costs) of acceptance and testing (or costs) of qualification.

Year	USA (US $)	Europe (Euro)	Japan (Mio.Yen)
2000	208700	190750	23.2
2001	214500	195900	23.8
2002	220500	201200	24.4
2003	226400	205600	25.0
2004	232100	210000	25.6
2005	238000	214200	26.3
2006	242700	219000	26.9

Figure 6.3. Historical cost of MYr vs geographic area.

The activities and testing (costs) of acceptance are those which are generated by the supply of an object on each of the objects to be delivered.

These tests are specifically aimed at verifying the proper execution of the manufacturing process for the object. In general, the loads associated with these tests are equal to the maximum loads considered possible during the course of the specific mission.

Simplifying this, we could say that if the object passes these tests, during the remaining part of its life (the operational mission) it will have to simply (at the most) support the same loads again, and practical experience shows that if an object works properly one time it is "probable" it will work a second time, as long as it is used under the same conditions (loads).

On the other hand, subjecting the element to be delivered (and which will have to fly) to higher loads than the one foreseen in flight, would create excessive risk and potential damage, just because of the testing done during the acceptance phase.

The activities, and qualification testing (costs) are instead those that are performed by the supplier on a single object, identical to the delivery ones and are aimed at demonstrating experimentally the existence of a "project margin" among the maximum loads foreseen in flight (the ones used in acceptance) and the item's capability of supporting higher loads, up to the level defined as "qualification."

From this definition, there is the fact that the object, which has undergone the qualification tests, cannot be used for the flight: its "survival" under the full force of the high qualification levels demonstrates the required project margin, but the object could reach "the limit of resistance" and therefore not be usable for the flight.

We can think of the Qualification tests as an "*exam*" of the design worthiness of the object.

"Cost Breakdown Structure"

In order to estimate the total cost of a complex system there are two main approaches (usually both used simultaneously):

Similarity approach, "Top down"

We attempt to start from a total preliminary cost obtained for similarities with already developed systems and whose cost and main features are known. Then corrective factors are introduced one by one which take into account the differences in cost linked to the differences among the characteristics of the systems: actual and similar. An alternative, if we do not have a total cost value available for similarity, is to start from the highest cost value which we consider allows the commercial use of the system. This total value is then apportioned on a series of values related to the parts making up the system (subsystems) in an attempt to go down to levels which allow the application of similarity of cost with already developed elements. At the end of this process, we evaluate the existence of subsystems where the apportioned costs are too low compared to an estimate based on similarity. If these cases do not exist, or if there are compensated by cases in which the apportioned cost is higher than the similarity cost, we can proceed to modify the initial estimate and to follow a second evaluation loop.

Aggregation approach, "Down-Top"

In this case, the complex system is subdivided into a series of minor-level elements (there can even be many levels: 4–10) up to the lowest level (i.e., simple), which can be estimated with reasonable approximation.

This tree structure which makes up the complex system is called "Cost Breakdown Structure" (CBS) and the total cost of the system is equal to the aggregation of costs of all elements of the CBS structure.

Cost Estimating Relationship

In order to estimate a cost, we often use a mathematical formula, Cost Estimating Relationship (CER), which gives the desired cost according to a few macroscopic parameters of the system, and which are usually already available during the initial phases of a project.

For example, in order to estimate the development and qualification cost of a liquid fuel motor with a turbopump, and ignoring for a moment corrective factors, the ratio used in [1] is:

- Development and Qualification Cost (in man-year cost) = 197.5 * M^0.52, where M is the mass, without fluids, of the motor system expressed in kilogram.

The CER shown was obtained on the basis of statistical analysis, as illustrated in Fig. 6.4.

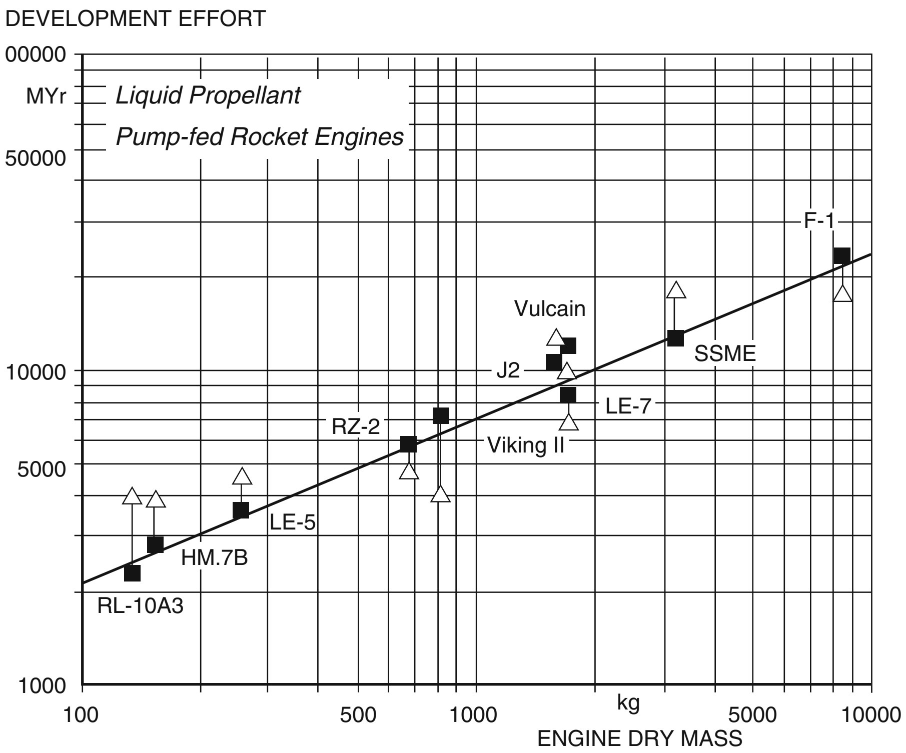


Figure 6.4. Typical CER for rocket motors from [1].

The Time Factor in Economic Analysis

It is probably superfluous to emphasize the importance of the time factor in the evaluation of the economic effects linked to the implementation of a project option. This is linked to the two main considerations which follow:

Money has a price (interest rate).
The price is a function of the reference geographical area, and the reliability characteristics of the requester (which is all a function of time).

Considering also the two different realization options of a system which have an equal value for total cost, they can be more or less convenient according to additional economic characteristics, including:

- Time of investment return
- Interest rate paid by the person borrowing money
- Average profit rate of the enterprise (i.e., it is wise to invest in this activity or not rather than in others?)

To make the evaluation of these economic effects simpler, various parameters have been defined which are presented, such as Return On Investment (ROI), Net Present Value (NPV) and others, and which are called "merit factors" of investment.

"Return On Investment"

It is one of the parameters used to judge the attractiveness of an investment. It is expressed as:

ROI = Operational result (of management; simplified = sales returns − total amount of costs) divided by the total amount of costs.

Comparing the forecast of the ROI with the cost of money we can have a rough idea of the program's attractiveness.

Direct and Indirect Costs

By direct cost, we mean a cost which can be attributed in a sure and distinct way to a single object of cost. Indirect costs, on the other hand, can be attributed to two or more objects of cost. Indirect costs must therefore be allocated to various objects of cost which arise assigning a weight of importance that each object has had in generating this cost; this weight commonly called allocation *coefficient* or *distribution coefficient*.

An example of indirect cost is related to general services such as administration, surveillance, etc., which are supplied, in parallel, on more than one program.

Technology Readiness Level

A number on the Technology Readiness Level (TRL) scale (common to both ESA and NASA) is used to indicate quantitatively the state of development of a specific

Table 6.1. Definition of the technology readiness levels (TRL)

Level	Definition
1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristics proof of concept
4	Component and/or breadboard validation in laboratory environment
5	Component and/or breadboard validation in relevant environment
6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
7	System prototype demonstration in a space environment
8	Actual system, completed and "Flight Qualified" through test and demonstration (ground or space)
9	Actual system "Flight Proven" through successful mission operation

technology beginning with the lowest level (knowledge of only basic principles) until the highest level (technology currently used in flight).

The TRL scale is shown in Table 6.1.

The achievement of levels up to 3–4 implies usually reduced costs; levels 5–8 are for the most part nonrecurring development costs (>80% of the total).

Level 9 is already part of the "life" of the technology in the commercial area and is no longer part of development.

Probability and Risk Aspects

The evaluation of probability and risk aspects make the "noble part" (and a difficult one) of technical-economic evaluations.

Many key decisions related to a program are those taken at the beginning of the program (i.e., the absolute first one is whether or not to do undertake the program); these decisions will be based on several certain data, but others might only be estimated.

Several examples, including those that determine the ROI and which are always estimated, are the following:

- The number of systems "sold" per year (depending on the price)
- The price of the sale of the system on the market (depending on the future market situation)
- The cost for realizing a system
- The cost of credit on the financial market (depends on the future financial market)

In the analysis of the attractiveness of a particular option of the system, for each of the parameters cited (and for many more which influence the technical-economic analysis) we can define a probability distribution for the same parameter.

It is therefore possible to carry out a statistical analysis, a "Monte Carlo" type, in which each of the input parameters is varied according to its own probability curve, and to finally elicit the probability distribution of the macroresults (see Fig. 6.5, Curve a).

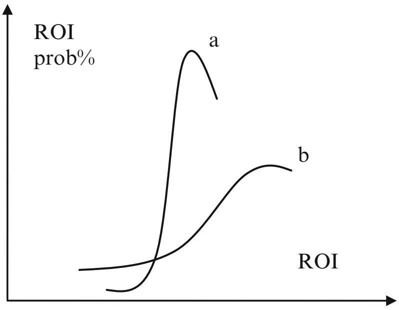


Figure 6.5. Probabilistic distribution of ROI.

The difficulty and criticality of the choices are evident in Fig. 6.5 which Curve "b" is relevant to a different realization option of the same system "a".

With only data taken into consideration it is not possible to choose between the option "b" (with higher max ROI and a broader distribution) and the option "a" (with a lower max ROI but a narrower distribution.

Commercial calculation systems widely available to perform these analyses and with stunning graphics should not give us a false impression of their own power. In fact, simulations are essential to allow the analyst to understand very quickly the relationships of influence between the various parameters in play, but by themselves do not give the best solution.

This solution always emerges from the fact that the analyst, dealing with the gathered data, asks himself the "*right*" questions, such as:

- How can I reduce the probability distributions of the parameters which influence the result (chosen merit figure)?
- How can I, acting on all the degrees of autonomy of the system under exam, eliminate/reduce the aspects which damage the merit figure chosen?
- Is the merit figure chosen actually the only (and absolutely) one which adequately represents the appropriateness = (it is never like this).

Comparison of the Cost of a Possible Failure and Cost for Increasing Reliability (and Therefore Decreasing the Probability of a Failure)

Nonrecurring costs, but also recurring ones (see for example the redundancy aspect), are very sensitive "*to the degree we want a system to be reliable*."

It is quite evident that the cost of a system is always higher as we require a higher reliability.

It is also understandable that increasing the reliability of a system, the number of flight accidents and mission losses will decrease, and with this decrease the cost of reutilization and associated insurance will go down.

The "engineering" problem is: when do we need "to stop" looking for always increasing reliability? The process of analysis is represented in Fig. 6.6 where "X" is identified as the optimal point.

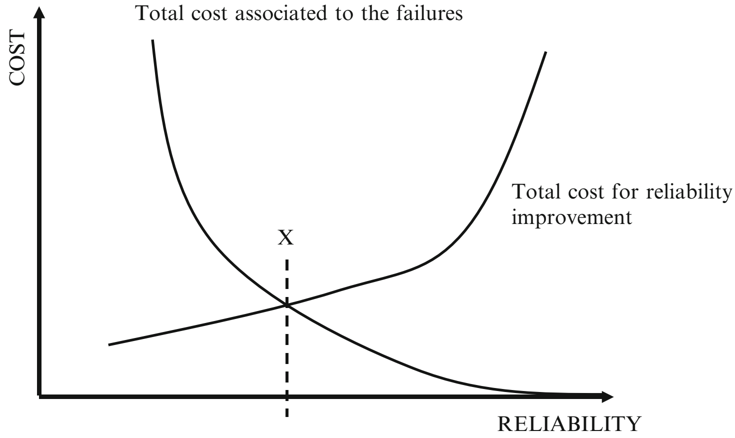


Figure 6.6. Cost optimization curve.

The practical problems, in applying the approach described above, are therefore to determine the optimal point "X," and are essentially the following:

- Difficulty in defining the total cost of failures, as seen by the same institution which must put out the funds for increasing reliability (i.e., if an "x" institution is the one that pays the increase of reliability and another institution, "y," is the one which must absorb the costs of mission failures, the reason fails, see footnote1).
- Insufficient applicable statistics in the space sector, and therefore there is not a good co-relationship between the increase in theoretical and effective reliability of the system.

"Life Cycle Cost"

This is a type of cost which examines the entire life of a system: from its conception, development, and qualification to its commercial operational life, and up to its "dismantling" (to be managed at the end of the commercial phase).

In formula: LCC = DDQC + PRODC + OPERC + DISPC where:

DDQC: "Design Development and Qualification Cost": is the total cost of the development and qualification phase.

PRODC: is the total production cost (i.e., of all the elements manufactured in the life of the system).

OPERC: is the cost of operations (both on ground and in flight) for the entire commercial duration of the product; it is made up of:

---

[1] In the European space sector, which is certainly not a purely commercial one, there have also been failures which prove to be economically advantageous for the industry which is responsible for them. This is on account of added financing measures put at their disposal to resolve the causes of the failures which occurred.

- DOC: Direct Cost Operations = sum cost of ground operations, material cost and propellant, in flight operations cost, transportation operations and recovery cost, rental and insurance cost.
- RSC: refurbishment and spare parts cost.
- IOP: indirect costs of the operations (are in general in flight costs, particularly significant for satellites because of their long-term Mission compared to the very brief time frame of a launcher).
- DISPC: is the "closing" cost of activities and facilities at the end of the system's commercial life.

Note: For a further detailing of costs which make up OPERC, see [1].

"Learning Curve" or "Learning Factor"

Experimentally and historically it has been ascertained that the cost of the first element developed is greater than the products (identical to the first one) realized afterwards. This is due to the accumulation of production experience which gradually reduces, even in a more contained way, the production costs of the single product.

Defining a "learning curve" called a "slope," $S = 95\%$, we mean that by doubling the products realized we obtain a reduction to 95% of the unit cost of production initially equal to a TFU value, whose mathematical formula is as follows:

L = learning factor = N^B where
N: total number of products (identical) realized
B = 1 − (ln(100/S)/ln(2)).

With such parameters we can express the following:

- The cost of production unit made up by N products = L*TFU
- Cost of the last product realized in the N series = ($L(N) - L(N-1)$)*TFU
- Average cost of the N product unit = TFU*L/N

Everything is represented in Fig. 6.7.

Net Present Value

One of the technical-economic trade-offs evaluations is related to comparing the options in which time of generating costs and returns is not identical.

In this case it is normal to utilize "cash-flow"—the flow of cash calculated as a return minus costs, in the time frame which, for a generic project, has the demonstrated development shown in Fig. 6.8.

Cash flow emphasizes the positive and negative flows of cash which occur in time.

We can calculate the "current" value (or for any date) of a financing foreseen on "x" (future) date, transporting it to the current date appropriately adapted to take into account the average foreseen development for the remuneration of capital from the current time to "x" time.

This current value is defined as the NPV, and can allow a comparison of options with various cash-flow developments and a different final value at the end of the program.

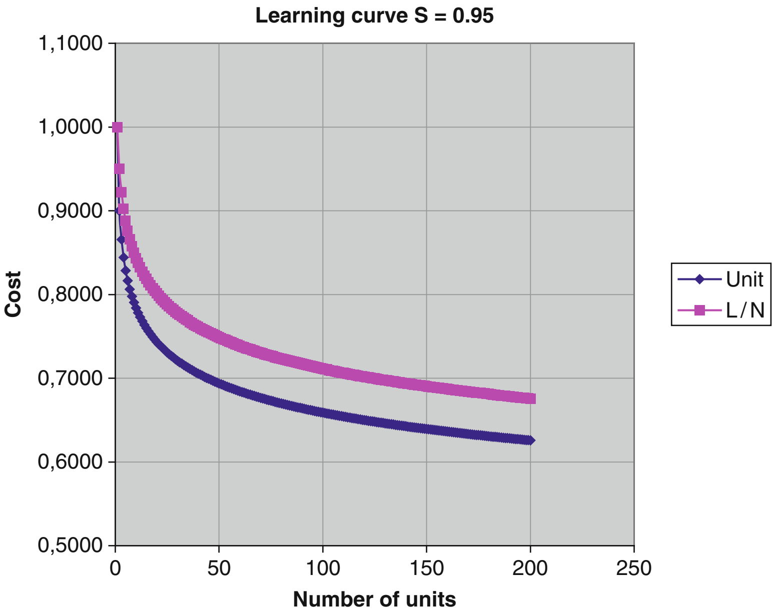


Figure 6.7. Unit and lot cost for a value of the learning curve of 95% (S).

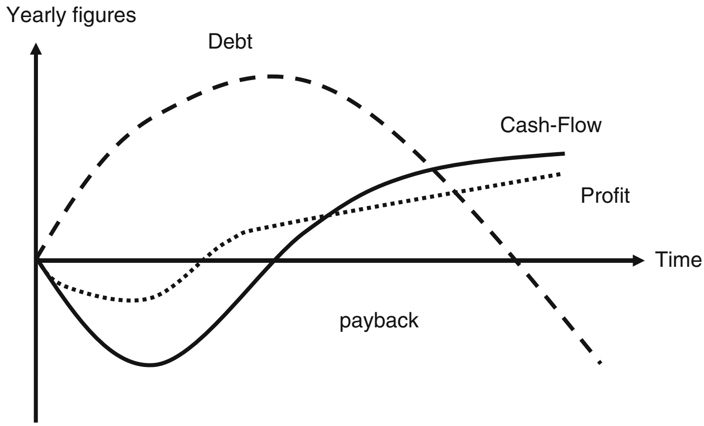


Figure 6.8. Cash-flow profile.

Measurement Criteria/Merit Figures

The choice of "measurement criteria" of the appropriateness/attractiveness of a particular realization and management option is perhaps the most critical aspect of a technical-economic analysis.

This is because there are many potential indicators of attractiveness, each one focused on emphasizing a particular aspect in the framework of the elements and economic-management characteristics.

For example, we can cite the following (in random order):

- Total development cost of the program
- Standard deviation of the total cost
- Life Cycle Cost (LCC)
- Standard deviation of the LCC
- Return On Investment ROI
- Standard of deviation on the ROI
- Time of return on investment (payback period)
- Total economic risk
- Total value (and visibility) of expected social benefits
- NPV
- Total financing quantity required
- Attractiveness of the investment for external financers
- Annual cash level flow and profit
- Minimum time of first-year profit (annual)

The choice of measurement criteria to be adopted depends greatly on the characteristics of the institution which finances, in particular, the binding conditions it places before it releases a financing (binding conditions regarding the market, binding conditions regarding partners, binding conditions regarding public opinion, binding conditions regarding government authority, etc.).

In general, it is a good idea to analyze the list of the most common indicators and select those which are considered the most important from the viewpoint of the one's own financing institution.

The final trade-off should be based on this close circle of merit figures, and further weighed in comparison with the relative importance of the indicators that varies in time: conditions of economic expansion or crisis, need to reduce debt, need for particular cash-flow profiles, etc.

6.3. The Business Plan

The Business Plan is the document which reports the quantitative analysis of the attractiveness of a technical-economic activity, which develops over several years. It constitutes the main document which guides the investment decisions on programs.

In its simplest form, it can be reduced to the economic-financial analysis table presented in Fig. 6.9.

In it are reported, for each of the 5 years assumed for the program, several basic parameters for evaluating the investment:

- The number of units (elements/objects) produced and sold
- The unit sales price
- The total returns
- The unit cost for the production of an element

And therefore the subsequent:

- Annual profit
- Cumulative profit since the beginning of the program

Year		1	2	3	4	5	Total
Number of units produced and sold (1)		5	10	10	10	20	55
Unitary Price (2)		20	20	20	20	20	N/A
Total Revenues (3)	'(1)*(2)	100	200	200	200	400	1100
Unitary cost (4)		18	18	18	18	18	N/A
Total cost (5)	'(4)*(1)	90	180	180	180	360	990
Yearly Profit	'(3)-(5)	10	20	20	20	40	110
Cumulated profit		10	30	50	70	110	

Figure 6.9. Simplified example of economic-financial analysis.

With the data from the table, in particular for the fact there is a positive profit value (and significant) for the each year of the plan, as well as for total integrated values in time, the investment appears attractive.

The representation of the investment shown in Fig. 6.9 does not, however, take into account numerous factors, several of which are briefly described as follows:

No identity between the number of units produced and sold each year

The units produced each year could not be all sold during the same year. In this case the relative costs would weigh on the plan while returns would not exist. This would bring about a reduction in the annual profit.

The existence of previous costs with respect to the manufacture of the first unit (i.e., development and qualification)

In particular for space programs, there is an extremely relevant cost for the long-term phase of development and qualification of a system and which must be completely supported before beginning the commercial phase of the system itself. This gives us a cost value which is (even much) higher than the one calculated in the figure.

The existence of costs associated with the sales process

In general, the commercialization of a product has costs (partially direct and partially indirect), which must be supported and which do not appear in the figure. They must be considered, and this further reduces the profit.

The presence of other indirect business costs: staff, administration....).

They exist and are indispensable for the operation of the structure which produces the system; not to consider them would overestimate real profit.

The existence of financial costs related to finding funds for development and qualification

The need to support the previous costs of sales (in general those related to development and qualification of the system) requires open financing with third parties. This has a cost in terms of interest which must be included with total costs. This factor usually becomes important in the space field because of the need for ingent financing and with particularly long-term repayment periods.

The existence of taxes

Taxes exist and should be considered (i.e., subtracted) in the calculation of the net profit deriving from the activity.

The existence of the alternative use of funds committed for the program under exam

Should the profits, as calculated taking into account all the above considerations, be zero, it would mean that the entire activity foreseen in the period would only be able to "pay for itself" and for costs related to the company. This is generally not enough because the company could have alternative uses for its technological and human resources that could lead to profits greater than 0. This is to say that to approve an initiative it must be verified that there are no more remunerative uses for the company resources (in the indicated period). In general new initiatives should have a profitability greater than the average profitability of the current company programs.

The existence of the need to remunerate the start-up financing of the Shareholders' company

Once more, in the case of zero profit of the previous case, there is the problem of remuneration of shareholders (or single contributing citizens) who have supplied the financing which created the technological, facility and human resources which make up the "assets" of the company. These assets (i.e., development of the company's market) constitute a mobilization of resources which must generate a profit. This profit usually has a minimum value which is linked to the one supplied by purely financial uses of the mobilized company assets. In other terms, it is reasonable to assume that the shareholders expect a profit (usually of medium-high risk) from a proposed industrial activity at least equal to the low-cost treasury bonds.

Once we have taken into consideration all of these phenomena, and we have updated the preceding table by introducing all the additional cost items, we suppose that there is a profit value which brings to a return of 17%, which is considered attractive compared to alternative uses of the proposed resources, and acceptable from the shareholders' perspective.

At this point there is a further limitation of the economic-financial analysis table presented: it does not state "what is certain" about the above calculated return. This is the critical limitation because it is evident that no worthwhile judgment can be offered without a quantitative and technically supported evaluation of the probability of obtaining the expected profit.

The approach is to go on to analyze a slightly more complex system, such as the one shown in Fig. 6.10.

We will analyze two problems separately:

1. *The interdependence of various input blocks of the financial model*

The most evident is between the market (which supplies the returns as a product of the sales price for the number of systems sold) and the unit price: the lower the price is, the higher the number of systems sold, with an impact on the value of returns.

Direct costs will be highly influenced by the number of systems sold, inasmuch as they go down significantly with the increase of production according to the so-called "learning curve" (see the dedicated section in section 6.2).

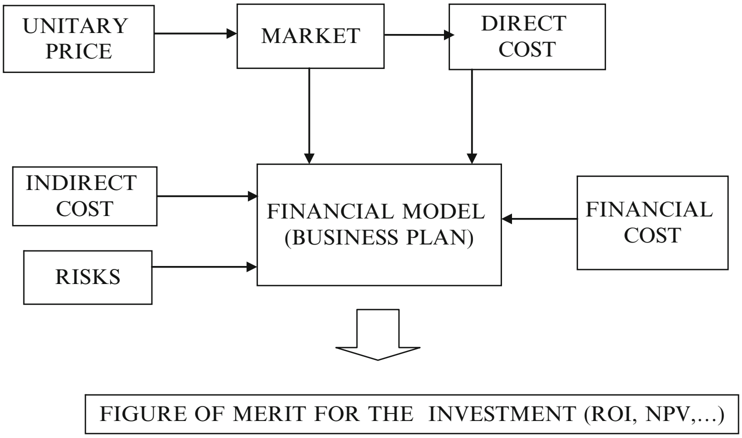


Figure 6.10. Calculation model for the attractiveness of an investment.

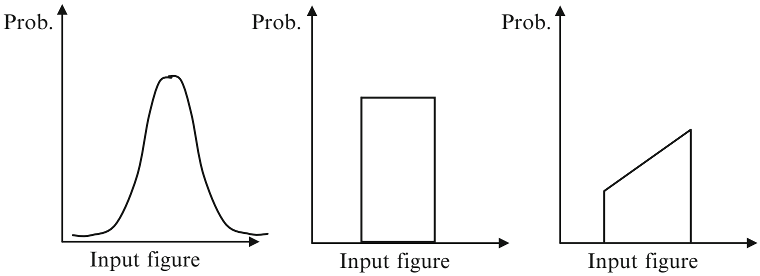


Figure 6.11. Examples of probabilistic distribution of input data.

Even the risks (of overcosts in production or of an interruption because of an in-flight failure) depend on financial burdens which have financed a more accurate (costly) or less accurate development and qualification phase of the system.

We can then find many other interdependencies going down to a level of greater detail of the model.

This problem is faced when we attempt to model mathematically each single interdependency and to define, through the use of an overall global model, the input which maximizes the best merit figure for the case being examined.

It is not superfluous to underscore that such mathematical relationships have a strong influence on the calculation of merit figures—for this reason they must be critically reviewed basing on the use of historical databases, or other means considered appropriate.

Finally, the need to relate a tolerance or validity margin to the mathematical models used must be taken into account, and must be used in the context of the following point.

2. *Probability distribution for each input supporting the most probable value*

Each of the financial model inputs results in a probability distribution, which must be accurately evaluated. Generally, we use the following distributions: Gaussian; uniform between a minimum value and a maximum value; and trapezoidal (between minimum and maximum), see Fig. 6.11.

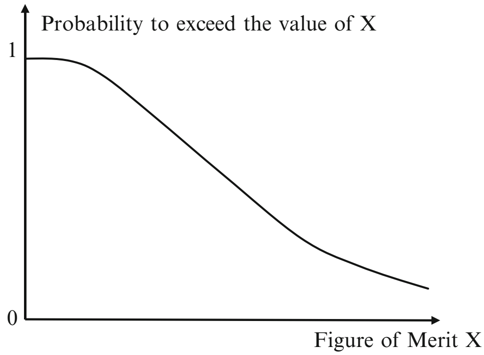


Figure 6.12. Typical (probabilistic) output figure.

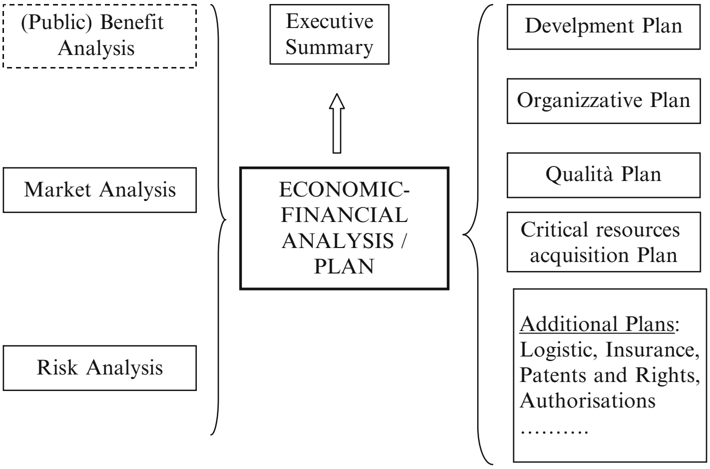


Figure 6.13. Business Plan typical architecture.

Having these probability inputs, we generate probability values for each merit figure in output.

The typical form of the probability function in output is shown in Fig. 6.12.

With the probability distribution of merit figures, we can compare various implementation options of a program, such as giving an overall judgment of merit regarding the option which is considered the most attractive.

Today, with the diffusion of Microsoft Excel-type software, the calculation of probability distribution of the merit figures is rather simple. As an alternative, there are commercial programs (@RISK type) which have been specially developed to carry out statistical analyses applied to the analysis of risks.

Alternatively, with a bit of practice with the use of an electronic spreadsheet and its macro functions, we can generate an efficient analysis instrument.

The business plan of a program of significant size has a rather complex structure like the one shown in Fig. 6.13.

The essential elements for the support of an Economic-Financial Analysis plan, which makes up the core of the Business Plan, are the following:

Profit Analysis

It is particularly important in the case of the public customer, where it is essential to "translate" the implementation of the program in terms of social benefit, and to do it (a) quantitatively, (b) in understandable terms to Public Administration. It is obvious that the quantitative evaluation of social benefits requires a series of hypotheses. Each of these must be listed, explained well, and supported quantitatively in terms of "credibility."

Market Analysis

It is the "motor" element of economic-financial analysis since it defines the level of returns (sales) without which no plan can support itself. In general, market analysis must define: a "global market" dimension (existing and foreseen in time), a subsection defined "potentially acquirable market" and further subsection which is called "probably acquired market." Even in this case, it is crucial to list and support each of the hypotheses introduced, possibly indicating their particular aspect of conservatism (or non-conservatism).

An important part of the market analysis is done through the identification and characterization of current and foreseeable competitors. In this context, sometimes the so-called SWOT—"Strength, Weaknesses, Opportunity and Threat"—analysis is included, which defines, for the proposed system, and with respect to the foreseen competitors:

1. Strong points
2. Weak points
3. Opportunities to be gathered
4. Threats (strategic/commercial) from which the company must be defended

It is very important that all those who work on drawing up the Business Plan have these points clearly in mind. In fact, each section of the Plan must systematically ask the question of how we can increase the strong points, reduce the weak points, take the greatest advantage of identified opportunities and protect the company from external threats.

Risk Analysis

Usually, a good indication of the Business Plan's accuracy is provided by examining the analysis of risks. This is because this analysis requires a balance between two opposing tendencies:

- Selecting, and defining, "credible" risks everywhere
- Minimizing risks taken into account by the analysis

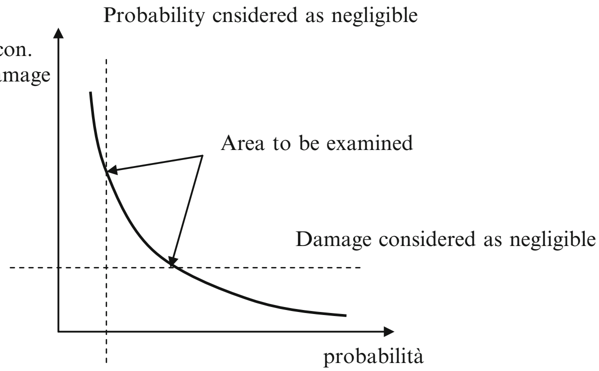


Figure 6.14. Typical diagram for evaluation of action priority.

It is evident that the first attitude leads to sidetracking the attention to risks which are really more critical for the program and therefore diluting the actions for overcoming risks which are intended to be used for contrasting them.

At the same time, it leads to penalizing heavily (inappropriately) the value foreseen for the program's attractiveness.

An example in the technical area is related to the drawing up of a "mass budget" of a system with a large number of the building elements; for each one it is appropriate to select a maximum credible value of the mass (in addition to the one defined as foreseen or nominal). However, it is not appropriate to evaluate the mass of the system as the sum of each of the maximum masses of the single elements; in fact, the probability that such "maximums" are realized contemporaneously is rather low (if the assigned nominal values are "in good faith"!!).

On the other hand, the second attitude (minimize) leads to ignoring effect and penalizing risks unjustifiably.

Risk analysis must therefore demonstrate equilibrium (that is experience) in considering all the risks which are the most significant in terms of impacts on business and the probability of occurrence.

Should direct experience not allow a certain selection of these risks, we can try to use the following approach:

- Consider all input parameters for economic-financial analysis as "at risk."
- Evaluate the effect of the shifting of each input parameter of the nominal value, in terms of impact on one/or more merit figures of the business.
- Approximately evaluate the probability of the shifting of the nominal input value described above.
- Construct a priority diagram of invention like the one shown in Fig. 6.14.

Development Plan

The development plan makes up the basis technical document of the Business Plan. It must describe the proposed system and its building parts (including product tree), in detail:

- Define the logic of "make or buy" of the building elements and their "heritage" (i.e., level of innovation and, consequently of the technical development risk). In particular, the decision to buy from an external supplier a subsystem ("Buy") or develop inside the proposing industrial structure ("Make") is tricky because it involves numerous aspects such as: cost of supplier compared to internal costs, level of strategicness of the sub-supply and therefore the dependence of the business on the elements which are out of the control of the Prime Contractor, level of workload of resources and facilities, technical adequacy, possible synergies with current or expected internal developments.
- Define the logic of development from the start-up of commercialization (including the list and technical motivation of the development models, with relative matrix of the material, the hardware matrix H/W matrix). The H/W matrix is the list of each part making up each of the system models foreseen for its development phase.
- Define the time of development (including planning in detail of all main activities of the program and which must point out logical connections, and input–output among the various activities).
- Define the structure of development costs, usually called CBS.
- Define the complete and reasoned list of "Ground Support Equipment" (GSE), which are the devices/equipment that are indispensable for realizing the proposed program. Examples of GSE are the following: transport containers, installations for the support or movement of specific pieces of the system, systems of integrated testing measurement to be performed on the complete system or on the building parts, systems for charging fluids or batteries, etc.
- Define risks of technical origin and the countermeasures foreseen in the plan not to make them critical.
- Define the structure of recurring production costs.
- Define the "Work Breakdown Structure" (WBS). The WBS is the structure which defines the subdivision of activities to be performed among various participating organizations and takes into account the type of work (technical activity, administrative activity, Quality activity, Manufacturing, testing, etc.).
- Define all work packages, WPs. The WP is the lower level element used to define the work to be performed and connects to a specific cost. A WP is part of only one element of the WBS (that is, it must be performed by only one organization and refers to a precise type of activity—for example, technical activity). Generally, it specifies in three main sections:

    1. Input
    2. List of detail activity
    3. Output

The initial information conditions necessary for performing the activity (1), the normally very detailed list of the single sub-activities to be performed (2), and lastly the result product of these activities (3). The result is generally the overall documentation, hardware, and software which must be singly identified in terms of required content as well as delivery date.

The Organization Plan

The organization or management plan must define in detail the responsible industrial structure of the program's implementation and the procedures foreseen for its operational functioning.

Essential elements of the plan are:

- Structure of the proposed industrial team and related responsibilities.
- Logic for establishing the industrial team and the specific competences of its members and the indispensable items, which result for the realization of the proposed program.
- Organizational structure in detail of the Prime Contractor, and specific structure defined within it for managing the program activities.
- Definition of all the interface positions among the participating organizations in the program.
- Synthetic definition of the main management procedures foreseen for the realization of the program (communication, approval and revision, formal meetings, control and cost management, invoicing, collecting money, development control, management of unforeseen circumstances, contract management, documentation, archive, transport and insurance, inventory….).
- Definition of management criteria of particular importance in technical framework, such as software management and management of configuration control.
- Definition of key figures of the program, with the presentation of their respective CVs.
- Payment plan and payment conditions. The payment plan is developed by reporting the value (price) of activities, the objective of the program, with respect to time. Under this plan the customer is asked to "pay" for the activities foreseen as the contractor must provide their financing. A payment at the beginning of the activities would be too risky and economically burdensome for the customer. Vice versa a payment at the end of the foreseen activity would be unsustainable by the contractor in terms of financial burden.

Note on payment conditions:

There are various possibilities regarding payment conditions (and new ones often arise). Several examples are reported as follows:

(a) *FFP: Firm and Fixed Price—Value in x currency which does not depend on the time payment is made.*
(b) *Value in x currency defined with reference to a specific year y. The actual payment is calculated re-evaluating the x value between the reference date and the current date of the payment. It is obvious that this type of condition is subdivided according to the different options regarding the re-evaluation criteria.*
(c) *Cost Reimbursement (reimbursement of sustained costs): the payment to be made is determined on the basis of costs formalized by the Contractor with the addition of a profit value x. Even this form can be subdivided according the time re-evaluation of the costs to be applied.*

(d) *"Mixed" systems; "cost reimbursement" type for one part, and FFP for another.*
(e) *Incentive—penalties: they are systems based on one of the previous ones, but which introduce a form of incentive or penalty linked to particular characteristics according to the development of the program.*

Typical characteristics which are the subject to incentive/penalty are the mass in orbit for a launcher, or the final delivery date of a system.

- List of key meetings of the program, such as the Design Review, or others
- List of the documents to be produced, and the delivery and approval plan
- List of deliverables, according to the program, whether H/W or S/W

Quality Plan

It reports the company standards concerning the critical processes for quality level guaranteed to the customer. In general, it is appropriate to issue an appendix dedicated to the program under examination, with the identification of regulatory specifications of "Quality" which the company intends to implement in case the program is acquired and with the purpose of guaranteeing an even more effective quality level, and a low level of risk.

Resource Availability Plan

Should all the human, financial, or technical (equipment and facilities) resources not be already available inside the organization for the implementation of a program, it is necessary to present an availability plan of these resources and to evaluate the risks associated to the availability process, with relative consequences.

This plan can be of major importance should there a complex process for its financing by third parties (shareholders, consortia, etc.) be required.

Finally, we should mention other specific plans which can be even more important according to the specific content of the proposed program:

- Logistics plan: it foresees and rationalizes all the activities inherent to material or human transport with regard to the program activities.
- Insurance plan: identifies and motivates all insurances and/or guarantees to be stipulated, or to take into account, in implementing the program.
- Patent and rights plan: identifies existing patents which can influence the technical implementation of the program.
- External authorization plan: identifies all those areas of activity, which could require authorization by third parties.
- "Decommissioning" plan, or closing activities: provided usually in nuclear or military space framework and aimed at necessary activities for "disposing"/making secure any material produced during the program and no longer necessary once it has ended. It should be noted that in some cases, such as the nuclear facility industry, costs linked to decommissioning are the crucial results for a proper evaluation of the business.

The Executive Summary

It is a brief document which reports the synthesis of all the main conclusions, drawn from the technical-economic analyses carried out, to evaluate the attractiveness of the program proposed from a global viewpoint.

It is the documentary "extract" which is delivered to the top management of the organization which must decide the financing of the program (even I have never seen a top manager take a decision in this sense, without having revised at least the economic-financial analysis in detail).

Stability in Time of Results Obtained from the Analyses: Physical Laws vs. Economic Convenience

The technical-economic analysis has a variability profile in time which is particular.

The technical part is usually based on physical laws which can be considered stable and on the availability of materials and technologies which are (moderately) variable in time.

It follows that the definition of the system from the viewpoint of its technical and cost/time for realization characteristics is stable enough in time.

On the contrary, the part related to the economic characteristics of the various possibilities of implementing the program can be highly variable in time faced with external events.

An organization (an industry or public agency) can suddenly find itself in conditions of extremely difficult access to credit (see global financial crisis of 2008–2009) and this is an example that would completely modify the relative weight of the merit figures described above.

This leads to the need to consider the technical-economic analyses as always being "instable", and the periodic need to reexamine them (during project phases) to identify promptly the presence of phenomena which can invalidate results, is highlighted.

Schema of Generic Technical-Economic Analysis

A generic technical-economic analysis is based on the following passages of general nature:

- A specific technical configuration of the system and its operations is theorized.
- A time plan for development and qualification of the system and the duration of the commercial phase (and dismantling, if applicable) are defined.
- All LCC linked to the configuration and commercialization are evaluated.
- Financial costs are added to the need for acquiring the necessary resources in time.
- Costs for unforeseen circumstances (connected to the risk level associated with the configuration under exam) are added.
- A corresponding sales plan is conceived and a particular price (it is calculated on a series of sub-cases derived from the so-called marketing model).
- Returns in time after sales are calculated and the cash-flow development is derived.
- Merit figures on the considered option are calculated.

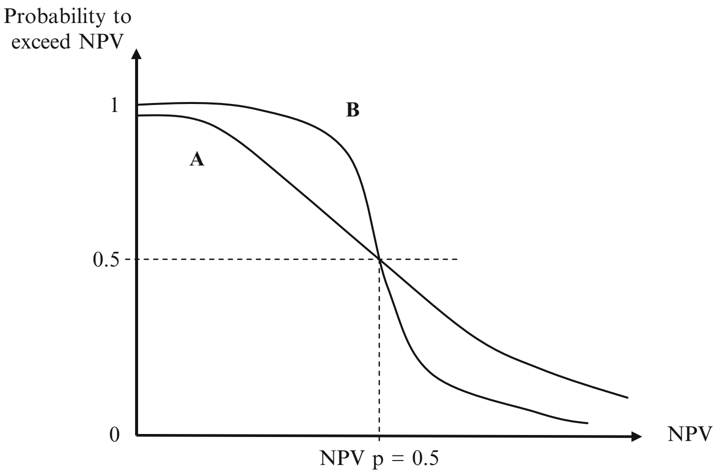


Figure 6.15. Net present value analysis.

- A statistical analysis of probability to evaluate the standard deviation is performed on the merit figures of greatest interest—see Fig. 6.1.5 whose merit is related to the sole value of the NPV.
- We return to the first step and analyze another option.

In the end we perform a trade-off analysis of the various options.

Note:

Figure 6.15 refers to two different technical-economic options for the realization of a system for which the most important criterion for the appropriate trade-off has been decided to be the maximization of Net Present Value.

It is important to note that option A is a major risk, and B is a minor risk (it might not in any case "automatically" be necessarily the best one).

It is important to observe that if we limited ourselves to calculating only the "most probable values" of the NPV of options A and B, these would be identical, thus *not allowing the evaluation of risk aspects* which highly differentiate the two examined options.

6.4. Example of Cost Analysis for a Space Launcher

One of the most important steps in generic technical-economic analysis presented above is made up of the calculation of costs, LCC, of a system.

The following paragraphs present an example case related to a launch system to be utilized for substituting satellites in the Galileo constellation for satellite navigation.

The method used has been defined in [1] and is based on the use of CER, and specific corrective factors of the application being examined.

Description of the program:

Consider two launches per year from the European base of Kourou for 20 years, with the objective of injecting in its final circular orbit about 23,000 km altitude and 56° inclination, 1 satellite at a time (1,000 kg weight at launch).

The launcher for the purpose of performing the mission weighs at launch about 398 tons and is configured as follows:

(a) First stage with a solid motor of about 107 tons (derived directly from ESA's Vega project) and four boosters of about 34 tons, of new design.
(b) Second stage with an analogous motor to the central first-stage motor.
(c) Third stage equipped with a new cryogenic oxygen motor and liquid methane about 14 tons and with 100 KN of thrust.

Cost analysis: ***INPUT***

Input data are data derived from the launcher characteristics and the ones of the industrial team that has the responsibility for development and qualification, as well as production of the launcher.

Table 6.2. Correction factors

Fattore	Nome	Valore
f0	Level of complexity of the Launcher	1.04^ stage number
f1	Available level of experience for the system to be developed	1.3–1.4: First generation systems, new concepts involving new technologies 1.1–1.2: New Systems with some new technical characteristics or operational approaches 0.9–1.1: Standard Systems at the State of the Art (similar systems are already operative) 0.7–0.9: Some modifications to an existing system 0.4–0.6: Minor changes to an existing system
f2	Level of technical quality of the System	Tab 2_11 liquid propellant engines (2-11) 1: SRM: not yet defined; 1 is suggested Propulsive modules: not yet defined Liquid Stages = NMF in TCS ref/NMF foreseen in the system
f3	Team Experience	1.3–1.4: New Team; no direct experience is available 1.2–1.2: Partly new activities for the foreseen Team 1: Team with experience applicable to the System to be developed 0.8–0.9: The Team has already carried out similar Project/Systems 0.7–0.8: Team has a consolidated experience in similar systems
f4	Learning factor	Read from Fig. 3-05 of [1], (see also definition of the learning curve at section 6.2) as function of the learning fct and of the number of identical units to be manufactured

(Continued)

Table 6.2. (Continued)

Fattore	Nome	Valore
f6	Optimal schedule	1.1–1.2: 70–80% of the schedule optimized for cost minimization 1.0–1.1: 80–100% of the schedule optimized for cost minimization 1: 100% of the schedule optimized for cost minimization 1.0–1.1: 100–120% of the schedule optimized for cost minimization 1.1–1.3: 120–140% of the schedule optimized for cost minimization 1.3–1.5: 140–160% of the schedule optimized for cost minimization 1.5–1.6: 160–180% of the schedule optimized for cost minimization
f7	Level of efficiency of the Industrial Organization	Number of "prime contractors"^0.2 The fct takes into account the fact that sometimes the simplest organization (namely one Customer and one prime Contractor) cannot be implemented due to external constraints. As example we can mention the development of the Ariane 5 Launcher where the classical role of Prime Contractor was split between CNES (system architect) and Aerospatiale (System responsible)
f8	Productivity	1 USA 0.86 ESA 0.77 France 0.77 Germany 0.7 Japan 2.11 Russia 1.5 China

For the very purpose of obtaining cost estimates which are realistic, the estimates calculated with CER developed in [1] are "adapted" to the industrial implementation context of the program, through a series of corrective factors such as those presented in Table 6.2.

The input in the example cited is shown in Figs. 6.16, 6.17, 6.18, 6.19.

Cost analysis: *calculation of development and qualification costs*

The calculation of development and qualification costs is developed with the following characteristic steps:

Step 1: definition of the CER for development and qualification.
Step 2: application of corrective factors to the CER.
Step 3: calculation of total development and qualification cost.
Step 4: calculation of the CER for production activity.
Step 5: application of corrective factors to the production CER.
Step 6: calculation of total production costs.
Step 7: calculation of flight and ground operations cost.

SECTION 0: INPUT						
LV conf name: P107 + 4B34 / P107 / HC14						
	GLOW (Mg) =	=	398			
1st stage						
motor	N. of qual firings	=	220	3 to 6 TCS standard for med-large SRM		
	Propulsion technology:	=	SOL			
	Propellant Mass (Mg):	=	107			
	f1 (tech develoment std)	=	0,7	1,3 to 1,4	First gen sys, new concept approach, involving new techniques and new techn.	
				1,1 to 1,2	New design with some new technical and/or operational features	
				0,9 to 1,1	Standard project, state of the art (similar systems are already in operation)	
				0,7 to 0,9	Design modification of existing systems	
				0,4 to 0,6	Minor variation of existing project	
	f2 (tech quality)	=	1	0,73	liquid propellant rocket engines (2-11)	
						i / ti / f2i / ti+1 / f2i+1
						2 / 200 / 0,7 / 300 / 0,85
				1	SRM: not yet defined; 1 is suggested	
					Propulsion modules: not yet defined	
					Liquid stages = NMF in TCS reference / NMF expected	
	f3 (team experience)	=	0,75	1,3 to 1,4	New team, no relevant direct company experience	
				1,1 to 1,2	Partially new project activities for the team	
				1	Company/ Industry team with some related experience	
				0,8 to 0,9	Team has performed development of similar project	
				0,7 to 0,8	Team has superior experiencewih this type of project	

Fig. 6.16. INPUT.

	f8 (productivity)	=	0,86	1	USA	
				0,86	ESA	
				0,77	France	
				0,77	Germany	
				0,7	Japan	
				2,11	Russia	
				1,5	Cina	
Boosters	N. of qual firings	=	5			
	Boosters number / LV	=	4			
	Propellant Mass (Mg):	=	34			
	f1(tech develoment std)	=	0,8	1,3 to 1,4	First gen sys, new concept approach, involving new techniques and new techn.	
				1,1 to 1,2	New design with some new technical and/or operational features	
				0,9 to 1,1	Standard project, state of the art (similar systems are already in operation)	
				0,7 to 0,9	Design modification of existing systems	
				0,4 to 0,6	Minor variation of existing project	
	f2 (tech quality)	=	1	#N/D	liquid propellant rocket engines (2-11)	
						i / ti / f2i / ti+1 / f2i+1
						#N/D / #N/D / ### / #N/D / #N/D
				1	SRM: not yet defined; 1 is suggested	
					Propulsion modules: not yet defined	
					Liquid stages = NMF in TCS reference / NMF expected	
	f3 (team experience)	=	0,75	1,3 to 1,4	New team, no relevant direct company experience	
				1,1 to 1,2	Partially new project activities for the team	
				1	Company / Industry team with some related experience	
				0,8 to 0,9	Team has performed development of similar project	
				0,7 to 0,8	Team has superior experiencewih this type of project	
	f8 (productivity)	=	0,86	1	USA	
				0,86	ESA	
				0,77	France	
				0,77	Germany	
				0,7	Japan	
				2,11	Russia	
				1,5	Cina	

Figure 6.17. INPUT.

2nd stage			
motor		N. of qual firings	=
	Propulsion technology:		=
	Propellant Mass (Mg):		=
	f1(tech develoment std)		=
	f2 (tech quality)		=
	f3 (team experience)		=
	f8 (productivity)		=
Identical to 1st stage			

Figure 6.18. INPUT.

3rd stage					
motor	N. of ground firings	=	200		
	Propulsion technology:	=	LCO		
	Vacuum Thrust level (kN)	=	10		
	Usable prop. Mass (Mg)	=	14		
	f1(tech develoment std)	=	1,1	1,3 to 1,4	First gen sys, new concept approach, involving new techniques and new techn.
				1,1 to 1,2	New design with some new technical and/or operational features
				0,9 to 1,1	Standard project, state of the art (similar systems are already in operation)
				0,7 to 0,9	Design modification of existing systems
				0,4 to 0,6	Minor variation of existing project
	f2 (tech quality)	=	0,7	0,7	liquid propellant rocket engines (2-11)
					i ti f2i ti+1 f2i+1
					2 200 0,7 300 0,85
				1	SRM: not yet defined; 1 is suggested
					Propulsion modules: not yet defined
					Liquid stages = NMF in TCS reference / NMF expected
	f3 (team experience)	=	1,1	1,3 to 1,4	New team, no relevant direct company experience
				1,1 to 1,2	Partially new project activities for the team
				1	Company/ Industry team with some related experience
				0,8 to 0,9	Team has performed development of similar project
				0,7 to 0,8	Team has superior experiencewih this type of project
	f8 (productivity)	=	0,86	1	USA
				0,86	ESA
				0,77	France
				0,77	Germany
				0,7	Japan
				2,11	Russia
				1,5	Cina
stage					
	f1(tech develoment std)	=	1,1	1,3 to 1,4	First gen sys, new concept approach, involving new techniques and new techn.
				1,1 to 1,2	New design with some new technical and/or operational features
				0,9 to 1,1	Standard project, state of the art (similar systems are already in operation)
				0,7 to 0,9	Design modification of existing systems
				0,4 to 0,6	Minor variation of existing project
	f2 (tech quality)	=	1		Propulsion modules: not yet defined
					Liquid stages = NMF in TCS reference / NMF expected
	f3 (team experience)	=	1,2	1,3 to 1,4	New team, no relevant direct company experience
				1,1 to 1,2	Partially new project activities for the team
				1	Company/ Industry team with some related experience
				0,8 to 0,9	Team has performed development of similar project
				0,7 to 0,8	Team has superior experiencewih this type of project
	f8 (productivity)	=	0,86	1	USA
				0,86	ESA
				0,77	France
				0,77	Germany
				0,7	Japan
				2,11	Russia
				1,5	Cina
LV assembly:					
	n: number of participating parallel org	=	1		
	f0	=	1,125	1,04^number of stages	
	f6	=	1,2	1,1 to 1,2	70-80% optimal schedule
				1,0 to 1,1	80-100% optimal schedule
				1	100% optimal schedule
				1,0 to 1,1	100-120% optimal schedule
				1,1 to 1,3	120-140% optimal schedule
				1,3 to 1,5	140-160% optimal schedule
				1,5 to 1,6	160-180% optimal schedule
	f7	=	1		
	f8	=	0,86	1	USA
				0,86	ESA
				0,77	France
				0,77	Germany
				0,7	Japan
				2,11	Russia
				1,5	Cina
	N: total number of (identical) Launchers	=	40		
Ground segment:					
	L: Launch rate (Launches/year)	=	2		
	N: Number of stages	=	3		
	fv: Launch Vehicle type fct	=	1		Cryoprop=1; Stor =0.8; 0.3= solid
					1= vert assy on LP; 0.7=vert assy + transp
	fc: LV asy & integration approach	=	1		to LP; 0.5= horiz. assy
	Q1: specific 1st stage fct	=	0,15		0.15=solid st; 0.4= exp liq prop or large boosters
	Q2: specific 2nd stage fct	=	0,15		0.15=solid st; 0.4= exp liq prop or large boosters
	Q3: specific 3rd stage fct	=	0,4		0.15=solid st; 0.4= exp liq prop or large boosters
Financial:	EURO/MYr change	=	2E+05		

Figure 6.19. INPUT.

They are developed as follows:

Step 1 Definition of the CER for development and qualification:

Figure 6.20 shows the calculation of the CER applied to the development and qualification of the booster.

SECTION 2: TOTAL DEVELOPMENT AND QUALIFICATION COST
SECTION 2.1: CER DEFINITION
Section 2.1.1: Booster

Propellant mass (Kg)=					34000 (1)	
NET Booster mass (Kg)=					2980	interpolated (2)
	i	pi	NMi	pi+1		Nmi+1
	12	30000	2700	40000		3400 (3)
Booster dev CER (MYr) =					**1332,404 (5)**	
*CER_ES =19,2*M^0,53 fig 2-06* (4)						

Figure 6.20. CER evaluation for the development of a solid propellant booster.

Table 6.3. Table 2-01 from [1]

Lift-off mass (mg)	Total development cost (KMYr)
100	20
200	27
300	32
400	38
500	42
600	45
700	50
800	52
900	55
1000	58
2000	80
3000	90
4000	100
5000	110
6000	120
7000	130

In order to clarify the type of presentation of the CER calculation, we add the following notes:

(1) Propellant mass (34,000 kg) is the base input for the CER; it is supplied to the INPUT/Booster section.
(2) It is the value of the dry mass of the Booster which is the value utilized in the mathematical formula of the involved CER. The value (2,980 kg) is calculated from Fig. 2-05 in [1], which was expressed in Table 6.3.
(3) Are the indices and partial values used for the linear interpolation of the data in Table 6.3.
(4) Is the mathematical ratio, from [1], which links the key parameter M (in this case the dry mass of the booster) to the CER.
(5) Reports the numerical value of the CER obtained with the mathematical formula (4). The CER related to the remaining parts of the launcher are presented in Fig. 6.21 and Tables 6.4, 6.5, and 6.6.

Section 2.1.2: First stage Engine

Propellant mass (Kg)=					107000	
NET SRM mass (Kg)=					11190	interpolated
	i		pi	NMi	pi+1	Nmi+1
		19	100000	10000	200000	27000
Motor dev CER (MYr)=					**2775,879**	
*CER_VR=4.9*M^0,68 fig 2-21*						

Section 2.1.3: 3rd stage engine

Vacuum Thrust lev (kN)=	100
Engine dev CER (MYr)=	**3105,294**
*CER_EL=197,5*M^0,52*	

Section 2.1.4: 3rd stage

Usable prop.mass (Mg)=					14	
Vacuum Thrust lev (kN)=					100	
Engine mass (Kg)=					200	interpolated
	i		Ti	Mi	Ti+1	Mi+1
		10	100	200	200	330
Stage NMF (%)=					17,8	interpolated
	i		pi	NMi	pi+1	Nmi+1
		3	10	19,5	20	15,25
Dry M with Eng (Kg)=					3031,63	
*Dry M with Eng (Kg)= NMF*Mprop/(1-NMF)*						
Dry M w/o Eng (Kg)=					2831,63	
Dry M w/o Eng (Kg)= Dry M with Eng - Engine mass						
Stage dev CER (MYr)=					**8123,762**	
CER_VE=98,6*M^0,555 fig 2-27						

SECTION 2.2: H PARAMETER DEFINITION (i.e. CER's with correction factors)

HE1: Dev of 1st stage SRM (MYr)=	1253,309
*HE1 = 1st stage engine CER*f1*f2*f3*f8*	
HE2: Dev of 2nd stage SRM (MYr)=	0
same motor of the 1s stage	
HE3: Dev of 3rd stage Engine (MYr)=	2261,958
*HE3 = 3rd stage engine CER*f1*f2*f3*f8*	
HB1: Dev of boosters (MYr)=	687,5203
*HB1 = Booster CER*f*f2*f3*f8*	
HV3: Dev of 3rd stage (MYr)=	9222,095
*HV3 = 3rd stage CER*f1*f2*f3*f8*	

Figure 6.21. CER evaluation for the other LV parts, and starting of step 2.

Table 6.4. Table 2-05 from [1]

Propellant mass (kg)	SRM burnout mass (kg)
1000	90
2000	180
3000	280
4000	380
5000	420
6000	510
7000	600

(Continued)

Table 6.4. (Continued)

Propellant mass (kg)	SRM burnout mass (kg)
8000	700
9000	800
10000	900
20000	1800
30000	2700
40000	3400
50000	4000
60000	5000
70000	6000
80000	7000
90000	8000
100000	10000
200000	27000

Table 6.5. Table 2-08 from [1]

Vacuum thrust (KN)	Engine mass (kg)
10	46
20	65
30	90
40	100
50	110
60	120
70	150
80	170
90	190
100	200
200	330
300	500
400	600
500	700
600	800
700	950
800	1050
900	1200
1000	1350
2000	2300
3000	3500
4000	4500
5000	6000

Table 6.6. Table 2-11 from [1]

No. of round firing test (development)	f2 factor
100	0.53
200	0.7
300	0.85
400	0.94
500	1
600	1.08
700	1.15
800	1.2
900	1.23
1000	1.29
2000	1.59

Table 6.7. Table 2-26 from [1]

Propellant usable mass (mg)	Net mass fraction (%)
8	21.8
9	20.5
10	19.5
20	15.25
30	13.5
40	12.5
50	12
60	11.6
70	11.25
80	11
90	10.75
100	10.5
200	9.5
300	9
400	8.75
500	8.5
600	8.4
700	8.2
800	8.1
900	8.05
1000	8

Step 3: calculation of total development and qualification cost Table 6.7.

The calculation of total cost of development and qualification of the launcher is presented in Fig. 6.22.

The almost totality of the costs of development and qualification in the third stage area (85%) is revealed. This is reasonable inasmuch the first and second stages have the same motor which is “almost existent”; only the boosters are to be developed.

SECTION 2.3 CALCULATION OF TOTAL DEVELOPMENT AND QUALIFICATION COST			
Cd:Total Development and Qualification cost (MYr) =		**15584**	
Cd=f0(HE1+HE2+HE3+HB1+HV3)*f6*f7*f8*		of which:	%
	Booster	798	5,12
	1st stage	1455	9,34
	2nd stage	0	0,00
	3rd stage	13331	85,54
		15584	100

Figure 6.22. Calculation of the total development cost.

Total dev cost as function of GLOW (Tab 2-01 Koelle):				**37880**	Interp tab 2-01
i		GLOWi	Cdi	GLOWi+1	Cd i+1
	3	300	32	400	38

Figure 6.23. Evaluation of the total development cost based on Table 2-01 of [1].

In order to verify the order of size of the costs of development and qualification obtained, we can use Table 6.3 which gives us the macroscopic correlation between weight at launch of the launcher ("GLOW" equal to 398 tons), and its development and qualification cost. This is demonstrated in Fig. 6.23.

The order of size is confirmed; the highest value supplied by the table is justified by the fact that the theoretical launcher is made up of element which are in part existing and by only the third stage which has to be developed.

Step 4: calculation of the CER for production activity.

The calculation of the CER for production activities is presented in Fig. 6.24, and Tables 6.8, 6.9, and 6.10.

Step 5: calculation and application of corrective factors to the production CERs.

The calculation and application of corrective factors to the production CERs is presented in Figs. 6.25 and 6.26.

Factor f4 keeps into account that as the identical units are produced, their unit production cost tends to decrease because of the accumulation of experience (see the part on the definition of the "learning curve" in section 6.2).

Therefore, to realize N units, the cost will not be N*CER, but rather N*CER*f4 (f4 $<$ 1). The calculation of factor f4 starts from the definition of learning factor "p": learning factor p (T.P. Wright 1936) equal to 0.8 (or 80%) means that by doubling the units produced, the unit cost will be reduced and assumes a value of 0.8 (80%) of the initial one.

A historical analysis of the values of p applicable to the space sector (and suggested by [1]) leads us to choosing values p between 0.8 and 1.0.

Clearly, factor f4 multiplied by the total number of elements produced, should not be considered the reduction factor applicable to the last element produced, but rather the average cumulative reduction factor should be calculated on the total for production (i.e., in the case of two elements produced with learning factor 0.8: the first one costs 1, the second one costs 0.8, but the average of the two is 0.9). In the case of the example shown, a value of $p = 0$ (90%) has been assumed.

SECTION 3: TOTAL PRODUCTION COST

SECTION 3.1: TFU CER DEFINITION

Section 3.1.1: Booster

NET Booster mass (Kg)=					2980	
Booster TFU (MYr)=					239,2	Interp tab 3-11
*from: FES = 2.42*n*M^0.395=*					228,1344	
	i		mi	TFUi	mi+1	TFUi+1
		12	2000	50	3000	60

Section 3.1.2: First stage Engine

NET SRM mass (Kg)=					11190	
SRM TFU (MYr)=					103,57	Interp tab 3-11
*from: FES = 2.42*n*M^0.395=*					96,18409	
	i		mi	TFUi	mi+1	TFUi+1
		16	10000	100	20000	130

Section 3.1.2 bis: Second stage Engine:

NET SRM mass (Kg)=	11190
SRM TFU (MYr)=	103,57

Section 3.1.3: 3rd stage engine

Engine mass (Kg)=					200	
Engine TFU (MYr)=					55	Interp tab 3-13
*from: FELC = 5.16*M^0.45*					55,99035	
	i		mi	TFUi	mi+1	TFUi+1
		8	200	55	300	65

Section 3.1.4: 3rd stage

Dry M w/o Eng (Kg)=					2831,63	
Stage level TFU (MYr)=					212,4234	Interp tab 3-17
*from: FVP = 1.3*M^0.65=*					227,912	
	i		mi	TFUi	mi+1	TFUi+1
		11	2000	175	3000	220

Figure 6.24. Evaluation of the production phase CER.

Table 6.8. Table 3-11 from [1]

SRM inert mass (kg)	TFU (MYr)
10	5
20	7
30	8
40	9
50	10
100	14
200	19
300	21
400	23
500	27
1000	38
2000	50
3000	60
4000	70
5000	76
10000	100
20000	130
30000	160
40000	190
50000	215
100000	300

Table 6.9. Table 3-13 from [1]

Inert motor mass (kg)	Cryo Eng. TFU(MYr)	Stor Eng TFU (MYr)
40	27	14
50	30	15
60	32	17
70	35	18
80	37	19.5
90	39	21
100	41	22
200	55	30
300	65	40
400	75	47
500	82	52
600	90	57
700	97	62
800	102	67
900	108	72
1000	115	75
2000	150	105
3000	185	130
4000	208	148
5000	220	160
6000	240	195
7000	260	205
8000	290	220
9000	310	230
10000	325	240

Table 6.10. Table 3-17 from [1]

Stage inert mass (without engines) (kg)	TFU Cryo (MYr)	TFU Stor (MYr)
100	26	16
200	39	23
300	50	32
400	60	39
500	70	43
600	80	50

(Continued)

Table 6.10. (Continued)

Stage inert mass (without engines) (kg)	TFU Cryo (MYr)	TFU Stor (MYr)
700	89	57
800	93	62
900	100	68
1000	105	70
2000	175	110
3000	220	140
4000	270	175
5000	310	200
6000	355	220
7000	400	240
8000	420	270
9000	480	300
10000	500	315
20000	800	515
30000	1020	700
40000	1200	820
50000	1400	950
60000	1600	1050
70000	1750	1100
80000	2000	1300
90000	2100	1450
100000	2200	1500

SECTION 3.2: "CORRECTED" CER DEFINITION (i.e. CER's with correction factors)
Section 3.2.1: Booster
FESb: (boosters production cost) (MYr) = **5190,611**
*FES = CER*N*f4*

Figure 6.25. Definition and adoption of the correction factors for the calculation of the production CER.

Step 6: Calculation of total production costs.
The calculation of total costs of production is shown in Fig. 6.27.

Step 7: calculation of flight and ground operations cost.
The calculation of flight and ground operations costs is presented in Fig. 6.28.

		n.of boost	160
f4 mean (boosters)=	0,542497	i =	160

Section 3.2.2: First stage Engine
FES1: (1st st SRM production cost)
(MYr)= **2749,029**
*FES=CER*N*f4*

f4 mean (1st st SRM)=	0,663568	i =	40

Section 3.2.2 bis: Second stage Engine
FES2: (2nd st SRM production cost)
(MYr)= **2749,029**
*FES=CER*N*f4*

f4 mean (2nd st SRM)=	0,663568	i =	40

Section 3.2.3: 3rd stage engine
FELc: 3rd stage engine prod cost (MYr)=
*FELC=CER*N*f4* **1459,849**

f4 mean (2nd st SRM)=	0,663568	i =	40

Section 3.2.4: 3rd stage
FVP: 3rd stage production cost (MYr)= **5638,292**
*FVP=ER*N*f4*

f4 mean (3rd stage)=	0,663568	i =	40

Figure 6.26. Definition and adoption of the correction factors for the calculation of the production CER.

SECTION 3.3 CALCULATION OF TOTAL PRODUCTION COST
CF:Total Production cost (MYr) = **18231,48**
CF=f0(FESb+FES1+FES2+FELC+ FVP)*
with f0=

	1,025	Ref Koelle, para 3.32	of which:	%
Booster			5320	29,18
1st stage			2818	15,46
2nd stage			2818	15,46
3rd stage			7276	39,91
			18231	100,00

Figure 6.27. Calculation of the total production cost.

The summary of the results in terms of complete life cycle cost (LCC) is reported in Fig. 6.29, in it:

- Column (1) reported the cost values expressed in MYr.
- Column (2) reports the cost values expressed in Meuro 2006.
- Column (3) divides the total costs expressed in Meuro on 40 launchers which make up the total quantity required in the input section.

SECTION 4: GROUND AND FLIGHT OPERATIONAL COST

OPERC (MYr) = DOC + RSC + IOC =		**575,621**	
Where:			
DOC: Direct operations cost	=	576	see para 4.1
RSC: Refurbishment and Spare cost	=	0	see para 4.2
IOC: Indirect Operations cost	=	0	see para 4.3
Section 4.1: Direct Operations cost (DOC):			
DOC (MYr) = GOP+M&P+F&M+T&R+F&I	=		**575,621**
Where:			
GOP: Ground Operations			
M&P: Materials and Propellants			
F&M: Flight and mission operations:			
T&R: Transport and Recovery ops			
F&I: Fees and Insurance			
Section 4.1.1 GOP Ground Operations			
CPLO (MYr) = 8*M0^0,67*L^ (–0,9)*N^0,7*fV*fc*f4 =	=	**338,8089**	
where:			
M0:GLOW (Mg)	=	398	
L: Launch rate (l/year)	=	2	
N: number of stages/LV	=	3	
fv:	=	1	
fc:	=	1	
f4:	=	0,663568	
Section 4.1.2 M&P Materials and propellants			
CM&P	=	0	negligible
Section 4.1.3 F&M Flight & Mission Operations			
CF&M (MYr) = CF&M (MYr/launch)* number of launches	=	**236,8121**	
CF&M (MYr/launch) = 20* (Q1+Q2+Q3)*L^(–0,65)*f4=	=	5,920302	
where:			
Q1: specific 1st stage fct	=	0,15	
Q2: specific 2nd stage fct	=	0,15	
Q3: specific 3rd stage fct	=	0,4	
L: Launch rate (Launches/year)	=	2	
f4:	=	0,663568	
Section 4.1.4 T&R: Transport and Recovery ops	=	0	No recovery op's
CT&R			
Section 4.1.5 F&I: Fees and Insurance	=	0	Not included
CF&I			
Section 4.2 RSC: Refurbishment and Spare cost	=	0	ELV system
Section 4.3 IOC: Indirect Operations cost	=	0	Under ESA budget

Figure 6.28. Calculation of the cost of the flight and round operations.

These values need further adaptation since they "would retain":

- That all development and qualification costs of the system (about 50% of total costs) are charged exclusively on the program (i.e., this leads to price increases of the launcher to recover investment).

		(1)	2006 (2)	(3)	
SECTION 1: SUMMARY OF RESULTS			Meuro	Meuro/LV	
LCC (MYr) = DDQC + PRODC + OPERC	=	**34392**	7532	188	
with:					
D DQC (MYr) : (Total) Dev and Qualification Cost	=	15584	3413	85	See section 2
PRODC (MYr): (Total) Production Cost	=	18231	3993	100	See section 3
OPERC: (Total) Ground and Flight Operations Cost	=	576	126	3	See section 4
			7532	188	

Figure 6.29. Summary of the results.

- That the number of launches is limited to the first batch of 40 launchers.
- That no economic value is assigned to be able to have a launcher that can perform other missions and be a strategic backup in case of the unavailability of another European launcher (i.e., Soyuz).

In particular, on the last point the possible economic evaluation of benefit is extremely complex and questionable; it can only be based on a political and social evaluation.

6.5. Example of Cost Analysis for a Satellite

One of the most well-known methods for defining development and qualification costs of a satellite is the one presented in [2], which is also based on the method of CER, with appropriate corrective factors.

Following is an example of the calculation developed for phase A of a prototype satellite.

Costs have been reported in kilo$ relative to the year 2000, as in [2].

Problem to Be Resolved

Evaluate the possibility, or not, of carrying out the development and qualification of a satellite system within a total fixed budget of 20 million $, and calculation of the budget related to the various areas (subsystems and main project activities).

Calculation Logic

Step (a): On the basis of the historical distribution of the data of costs for satellite development, the total available is apportioned on various cost items.

Step (b): corrective factors are introduced to take into account the project characteristics and the industrial team which must develop them.

Step (c): we analyze the technical-economic feasibility of each cost item within the budget assigned (through the use of specific CERs).

Table 6.11. Overall data at satellite level

S/C total cost (FY$K)=	6,200	First Iteration
S/C bus dry mass (kg)=	100	
Structure mass (kg)=	25	
Thermal control mass (kg)=	5	
Average power (W)=	70	
Power system mass (kg)=	30	
Solar Array Area (m2)=	2	
Battery capacity (Ah)=	20	
BOL power (W)=	250	
EOL power (W)=	250	
TTC S/S mass (kg)=	3	
Dowlink datarate (Kbps)=	500	
TTC DH mass (kg)=	0	
Data storage capacity (MB)=	20	
AOCS dry mass (kg)=	15	
Pointing accuracy (°)=	0.25	
Pointing knowledge (°)=	0.1	
Satellite volume (M3)=	1	
Number of RCT's (-)=	6	

Step (d): we verify if the items whose apportioned cost is over the one foreseen is compensated from those in which the contrary occurs and, otherwise, we perform a second loop after having introduced simplifications to reduce the cost of elements which are the most critical.

Macroscopic Data at the Satellite Level

The base macroscopic data to the design of the satellite are presented in Table 6.11.

Distribution of Development and Qualification Costs on Various Areas of the Satellite Product

Step (a): The generic percentage division of relative costs of development and qualification are presented in Table 6.12 and from [2].

Step (b): In order to take into account the level of available experience by the industrial team responsible for the development and qualification of the satellite, we define the table of corrective factors shown in Table 6.13.

Assuming an initialization value of cost for development and qualification (without introducing corrective factors) of 17,000 K$, we obtain the distribution of costs shown in Fig. 6.30.

Table 6.12. Percent distribution of development cost from [2]

Subsystem activity	Fraction of S/C bus cost %	NRC %	RC %
1.0 Payload	40.0%	60.0%	40.0%
2.0 BUS Total	100.0%	60.0%	40.0%
2.1 Structure	18.3%	70.0%	30.0%
2.2 Thermal	2.0%	50.0%	50.0%
2.3 Electrical Power System	23.3%	62.0%	38.0%
2.4a TT&C	12.6%	71.0%	29.0%
2.4b C&DH	17.1%	71.0%	29.0%
2.5 ADCS	18.4%	37.0%	63.0%
2.6 Propulsion	8.4%	50.0%	50.0%
WRAPS			
3.0 IA&T	13.9%	0.0%	100.0%
4.0 Program level	22.9%	50.0%	50.0%
5.0 GSE	6.6%	100.0%	0.0%
6.0 LOOS	6.1%	0.0%	100.0%
Total	189.5%	92.0%	97.5%

Table 6.13. Correction factors for the satellite development cost

	Heritage code	Heritage Fct	Ref range
New design with advanced development	0	1.50	>1.1
Nominal new design—some heritage	1	1	1
Major modifications to existing design	2	0.8	0.7–0.9
Moderate modifications	3	0.5	0.4–0.6
Basically existing design	4	0.2	0.1–0.3

The following notes should be considered:

The table apportions the total value of the first loop (17,000 K$) on various cost items, based on values % drawn from step (a)

The second column defines the “experience” factor considered applicable to the project examined, according to the code defined in step (b)

The Detail columns are used to obtain the detail of the subsystem level and to effect a control on the apportioned value to the higher level (Bus total)

Introducing the corrective factors, we obtain the costs presented in Fig. 6.31, always expressed in FY00K$ (“Fiscal Year 2000 US $”).

Input RTDE+TFU cost (FY00$K) = 17000
Output without heritage factor:

Subsystem Activity	Dev Heritage code	RTDE+TFU	detail	NRC	detail	RC	detail	*Check*
1.0 Payload	0	3588,39		2153,03		1435,36		*3588,39*
2.0 BUS Total	3	8970,98		5382,59		3588,39		*8970,98*
2.1 Structure	2		1641,69		1149,18		492,51	*1641,69*
2.2 Thermal	3		179,42		89,71		89,71	*179,42*
2.3 Electrical Power System	3		2090,24		1295,95		794,29	*2090,24*
2.4a TT & C	3		1130,34		802,54		327,80	*1130,34*
2.4b C & DH	3		1534,04		1089,17		444,87	*1534,04*
2.5 ADCS	3		1650,66		610,74		1039,92	*1650,66*
2.6 Propulsion	2		753,56		376,78		376,78	*753,56*
WRAPS						0,00		*0,00*
3.0 IA & T	1	1246,97		0,00		1246,97		*1246,97*
4.0 Program Level	3	2054,35		1027,18		1027,18		*2054,35*
5.0 GSE	2	592,08		592,08		0,00		*592,08*
6.0 LOOS	3	547,23		0,00		547,23		*547,23*
TOTAL		**17000,00**						
				9154,88		7845,12		**17000,00**
Note: unit as per input								
		check:	*8979,95*		*5414,07*		*3565,87*	

Figure 6.30. Cost distribution assuming a first loop figure of 17,000 K$.

Output with heritage factor:

Subsystem Activity	Dev Heritage factor	RTDE+TFU	detail	NRC	detail	RC	detail	*Check*
1.0 Payload	1,5	5382,5858		3229,551		2153,034		*5382,586*
2.0 BUS Total	0,5	5208,5488		3164,826		2043,723		*5208,549*
2.1 Structure	0,8		1313,351		919,3456		394,0053	*1313,351*
2.2 Thermal	0,5		89,70976		44,85488		44,85488	*89,70976*
2.3 Electrical Power System	0,5		1045,119		647,9736		397,1451	*1045,119*
2.4a TT&C	0,5		565,1715		401,2718		163,8997	*565,1715*
2.4b C&DH	0,5		767,0185		544,5831		222,4354	*767,0185*
2.5 ADCS	0,5		825,3298		305,372		519,9578	*825,3298*
2.6 Propulsion	0,8		602,8496		301,4248		301,4248	*602,8496*
WRAPS								
3.0 IA&T	1	1246,9657		0		1246,966		*1246,966*
4.0 Program Level	0,5	1027,1768		513,5884		513,5884		*1027,177*
5.0 GSE	0,8	473,66755		473,6675		0		*473,6675*
6.0 LOOS	0,5	273,61478		0		273,6148		*273,6148*
TOTAL		**13612,559**		**7381,633**		**6230,926**		

Figure 6.31. Cost distribution after the adoption of the correction factors.

As we can see, the total is decreased because of the availability of consistent experience applicable to the proposed system. The Payload is an exception because it passes from 3,588 to 5,382 FY00K$ because of its lack of experience in the specific field.

Step (c): The technical and economic feasibility is presented in Fig. 6.32.

RDT&E and Theoretical First Unit (Table 20-6 SMAD Iss.3)

Cost Component	Parameter ID X	Param Val.	Input data range	S/S cost CER	S/S cost FY00$K	Dev Heritage factor	S/S cost FY00$K w corr fct	totals
a	b	c	d	e	f	g	h	i
1.0 Payload	S/C total cost (FY$K)=	6200	1922-50651	0,4*X	2480	1,5	3720	3720
2.0 BUS Total	S/C bus dry mass (Kg)=	100	20-400	781+26,1*X^1,261	9463	0,5	4732	
2.1 Structure	Structure mass (Kg)=	25	5-100	299+14,2*X*Ln(X)	1442	0,8	1153	1153
2.2 Thermal	Thermal Control mass (Kg)=	5	5-12	246+4,2*X^2	351	0,5	176	157
	Average power (W)=	70	5-410	-183+181*X^0,22	278	0,5	139	
2.3 Electrical Power System	Power System mass (Kg)=	30	7-70	-926+396*X^0,72	3658	0,5	1829	2238
	Solar Array Area (m2)=	2	0,3-11	-210631+213527*X^0,0066	3875	0,5	1938	
	Battery capacity (Ah)=	20	5-32	375+494*X^0,754	5103	0,5	2552	
	BOL Power (W)=	250	20-480	-5850+4629*X^0,15	4747	0,5	2373	
	EOL Power (W)=	250	5-440	131+401*X^0,452	4995	0,5	2498	
2.4a TT&C	TTC S/S mass (Kg)=	3	3-30	357+40,6*X^1,35	536	0,5	268	860
	Dowlink datarate (Kbps)=	500	1-1000	3636-3057*X^(-0,23)	2904	0,5	1452	
2.4b C&DH	TTC DH mass (Kg)=	0	3-30	+484+55*X^1,35	484	0,5	242	835
	Data storage capacity (MB)=	20	0,02-100	-27235+29388*X^0,0079	2857	0,5	1428	
2.5 ADCS	AOCS dry mass (Kg)=	15	1-25	+1358+8,58*X^2	3289	0,5	1644	2453
	Pointing accuracy (deg)=	0,25	0,25-12	+341+2651*X^(-0,5)	5643	0,5	2822	
	Pointing knowledge (deg)=	0,1	0,1-3	+2643-1364*ln(X)	5784	0,5	2892	
2.6 Propulsion	S/C bus dry mass (Kg)=	100	20-400	+65,6+2,19*X^1,261	794	0,8	635	1345
	satellite volume (M3)=	1	0,03-1,3	+1539+434*ln(X)	1539	0,8	1231	
	Number of RCT's (-)=	6	1-8	+4303-3903*X^(-0,5)	2710	0,8	2168	
WRAPS								
3.0 IA&T	S/C total cost (FY$K)=	6200	1922-50651	+0,139*X	862	1	862	862
4.0 Program Level	S/C total cost (FY$K)=	6200	1922-50651	+0,229*X	1420	1	1420	1420
5.0 GSE	S/C total cost (FY$K)=	6200	1922-50651	+0,066*X	409	1	409	409
6.0 LOOS	S/C total cost (FY$K)=	6200	1922-50651	+0,061*X	378	1	378	378,2
TOTAL								**15830**

Figure 6.32. Technical–Economical feasibility analysis.

Comparison between allocation and cost estimate
Cost expressed in FY00K$

Subsystem Activity	Allocation RTDE+TFU	detail	Cost estimate RTDE+TFU	detail	C/E %
1.0 Payload	5383		3720		69,11
2.0 BUS Total	5209		9041		173,58
2.1 Structure		1313		1153	87,82
2.2 Thermal		90		157	175,26
2.3 Electrical Power System		1045		2238	214,12
2.4a TT&C		565		860	152,16
2.4b C&DH		767		835	108,89
2.5 ADCS		825		2453	297,16
2.6 Propulsion		603		1345	223,06
WRAPS					
3.0 IA&T	1247		862		69,11
4.0 Program Level	1027		1420		138,22
5.0 GSE	474		409		86,39
6.0 LOOS	274		378		138,22
TOTAL	**13613**		**15830**		**116,29**

Figure 6.33. Comparison of allocated vs expected cost (CER based).

Column Legend

(a) Indicates the cost item which is the object of the estimate
(b) Indicates the physical parameter on the basis of the mathematical formulation of the CER.
(c) Indicates the value of the physical parameter defined in column b
(d) Indicates the validity range of the physical parameter within which the CER value obtained is to be considered reliable
(e) Indicates the mathematical formulation of the CER
(f) Expresses the numerical value of the CER, with the application of the corrective factor
(g) Indicates the corrective applied and derived from the preceding table
(h) Expresses the numerical value of the CER, with the application of the corrective factor experience
(i) Expresses the unit values per single cost item present in column a.

In particular, the cost estimate relative to several S/S can be performed on the basis of various parameters, according to which the technical aspects of the S/S become design (cost) driver of itself. The totals reported in column "I" are obtained by performing a simple arithmetic average on the various partial available evaluations.

This approach is simple, but in a more appropriate way, it should be evaluated which aspect of the S/S can constitute the effective driver and "shift" the estimated cost closer to the estimate related to this parameter.

Step (d): The comparison between the apportioned economic budget and cost estimate of the CER is presented in Fig. 6.33.

This table compares the cost values deriving from simple apportionment, to those drawn from the estimate based on the CERs.

We can see that the total values are not very different, while the relative values of several subsystems diverge: ADCS, Propulsion and Electrical Power.

A second loop analysis is in general needed to evaluate where the apportioned value is more appropriate or the estimated value of the CERs.

6.6. Criteria for Reducing Costs

There now exists a consistent margin for reducing costs in the space framework; in particular concerning development and qualification costs.

Many program managers have performed analyses aimed at selecting the necessary actions to perform cost reduction.

The most important of all of them, however, is to diffuse, from the lowest operational level, a real "sensitivity" to the search for approaches and actions which can reduce costs. Especially in Europe, at least 90% of technicians operating in the sector do not *really* have the objective of reducing costs through their work and their creativity.

This feeling is verifiable if we ask many of these technicians what they think is possible (obviously with secondary risks) to reduce costs on the system they are working on. The answer is usually not immediate, but after reasoning one or more hypotheses are always pointed out.

These hypotheses are not usually (by the involved person) "publicized" or discussed or expressed to superiors.

What is the reason for this attitude? The answer is not specific, but denotes, in general, surprise by the person who has no idea it can be important, or at least significant.

The following are reported on next pages:

(a) Considerations on the origin of potentially reducible costs.
(b) Guidelines for realizing a development program of a reduced cost launcher.
(c) What has been applied as reference to "Lockheed Martin" to obtain reduced development costs and, finally.
(d) The experiences, lessons learned, by Italian industry in the framework of developing the European launcher Vega and the preliminary results obtained.

(a) Reference [3] refers, at section 6.2, the main factors which have generated extra costs which are not technically justifiable:

  1. Forms of management duplication between customer and Prime Contractor with subsequent over sizing of the industrial team to have all the proper interfaces with the customer
  2. Management procedures which are not sensitive to the cost aspect, in particular:

     Over specification (over-abundant requirements and partially useless)
     Excessive progress reports (even one per week!)
     Excessive formal meetings—Design Reviews
     Excessive documentation
     Excessive concern for traceability (in development and qualification phase)

Excessive bureaucracy in the management of contract changes

3. Aversion to risk acceptance (systematic use of verification only through tests)
4. Excessive duration of the program, caused especially by:
   - Long acquisition phase of the program
   - Frequency of stops/slowdowns and resumption of program activities
   - Duration of approval procedures
5. Tendency to expect the optimality of any technical solution with the subsequent rare use of existing material
6. Strong subdivision of activities over several sequential contracts instead of only one of greater size.

(b) Reference [4] instead reports in Table 1–3 the following methods for realizing a significant reduction in costs:

Accurate critical review of requirements, see (a2)
Concurrent Engineering
"Design to Cost"
Reduction of development time, see (a4)
Reduction of the impact of possible negative circumstances, see (a3)
Use of microprocessors
Introduce relevant margins to reduce testing, see (a3)
Use existing material also not of space origin, see (a5)
Use highly autonomous systems
Use components and standard interfaces, see (a5)

(c) The basic criteria defined instead by Lockheed Martin ["skunk works rules," see note (1)] are as follows:

Strong management of the program with complete authority
Reduced management team by the Customer, and with full authority reduced number of participating contractors to the team (but experts)
Release system of designs, streamlined
Reduced documentation
Systematic review meetings on costs
Prime contractor directly responsible of his/her subcontractors
Elimination of duplication in inspections
Final control of the customer in flight mission
Time stability of requirements
Regular and adequate release of funding
Mutual respect between the Prime Contractor and the customer
Reduction of outside environmental disturbances as much as possible
Economic bonuses system in case of excellence

Note (1): The definition from the web is the following:

*Skunk Works is an official alias for **Lockheed Martin's** Advanced Development Programs (ADP), formerly called Lockheed Advanced Development Projects. Skunk Works is responsible for a number of famous aircraft designs, including the **U-2**, the **SR-71**, the **F-117**, and the **F-22**. Its largest current project is the **F-35 Lightning II**,*

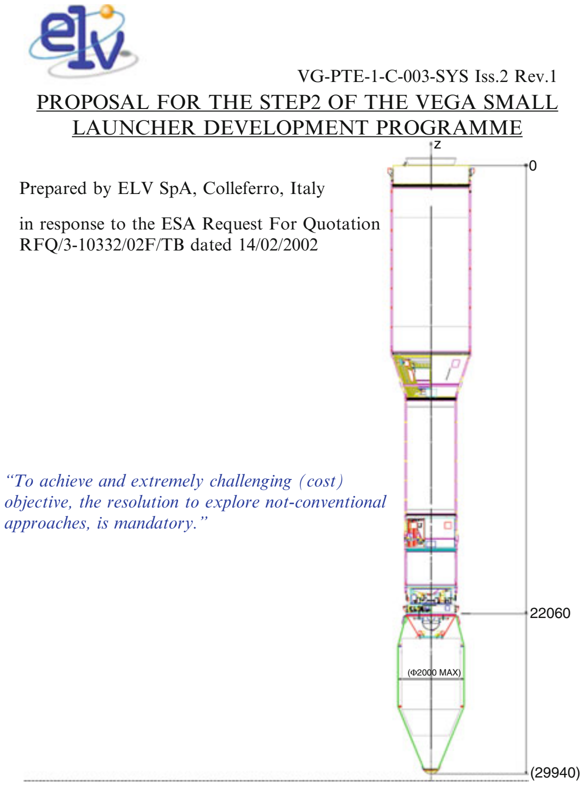


Figure 6.34. Cover page of the Vega Launcher implementation proposal (reproduction under Avio SpA and ELV SpA authorization).

which will be used in the ***air forces*** *of several countries around the world. Production is expected to last for up to four decades.* ***"Skunk works" or "skunkworks"*** *is widely used in business, engineering, and technical fields to describe a group within an organization given a high degree of autonomy and unhampered by bureaucracy, tasked with working on advanced or secret projects.*

(d) What we have achieved with the Vega program

At the beginning of the development of the European launcher Vega, the ELV company (a joint company between the Italian Space Agency and the Avio group, at that time owned by FIAT SpA) acting as Prime Contractor of the program for the customer (the European Space Agency ESA) had clearly selected a criticality in development costs [5]; it also had identified the need for a drastic change in the point of view of the design and management of the program. This was well represented in 2000 on the cover page of the formal offer for the development and qualification of the launcher, as shown in Fig. 6.34.

The management plan defined at that time foresaw the implementation of many recommendations developed in the US framework already cited, and adapted to its use in European framework.

Table 6.14. Economic efficiency of the Vega approach applied to the SRM development

	(1) Reference cost at ESA/NASA/GOV (full) standards	Order of magnitude of cost for Vega scenario
Total development cost of the Launch Vehicle	100	10–20 (2)
Total development cost of the first stage SRM (90t class)	100	20–30
Total development cost of the second stage SRM (23t class)	100	20–30
Total development cost of the third stage SRM (10t class)	100	20–30 (3)

We have not been able to implement all the above recommendations, but even the introduction of only several of them have brought about extremely significant results and which prove the economic efficacy of a modest discontinuity with respect to design standards, but especially in management, considered established in the European space framework in the last two decades.

It is possible to synthesize as shown in Table 6.14.

The following clarifications should be added:

(1) As the first approximation the [1] calculates the development and qualification costs of a launcher on the basis of its weight at takeoff: The column reports these values (normalized to the value of 100).
(2) Favorably feels the effects of the characteristic of particular simplicity of the Vega project (launcher with 3 stages with solid propellant and a liquid propellant stage) compared to Ariane 5 class launchers, much more complex and designed also for human flights.
(3) The cost includes those related to variances occurring in development phase, and to the implementation of all recovery measures and requalification.

References for Chapter 6

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3. Greenberg, J.S.: Economic Principles Applied to Space Industry Decisions. Zarchan, P. editor in chief, AIAA, Washington, D.C. (1992)
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Chapter 7

Financial Management of Space Programs

In this chapter the financial aspects of space programs will be analyzed, meaning the available forms of financing for them with particular reference to private financing and the methods and tools of commercial, economic-financial evaluation in space programs.

Finally, a practical case will be presented as an example, a "business case," with the objective of highlighting the critical factors of success for investment projects in the space sector.

7.1. Forms of Financing for Space Programs

Forms of financing for space projects can be essentially subdivided into three categories:

- Public financing, where the financial coverage of the project is directly or indirectly guaranteed by the government's budget, normally on a multiyear basis.
- Private financing, the project is financed through the contribution of private capital both on the basis of corporate financing and through the use of financial project tools ("project financing" type).
- Public–private co-financing; financial coverage of the project is guaranteed through public and private financing with a definite mix on the basis of the nature of the initiative which is the aim of the investment and the economic-financial return.

Public funding includes three types of actions:

- Those referred to as capital account expenses, or public investments to be realized in several successive parts by single Ministries.
- Those regarding international projects, or developed by public agencies with international rights such as the European Space Agency ESA, the European Union, the European Southern Observatory (ESO), and other similar institutes.
- The one relative to national agencies, such as the Italian Space Agency, the French CNES, the German DLR, the American NASA, etc.

The first type includes capital account expenses carried out by Ministries. These expenses require a law of authorization, their registration in the budget, and relative financial coverage which guarantees the previous evaluation of the impact on expenses foreseen on public funds.

M. Spagnulo et al., *Space Program Management: Methods and Tools*,
Space Technology Library 28, DOI 10.1007/978-1-4614-3755-0_7,

On the other hand, concerning the allocation of funds, this is done in the execution of the forecast budget through procedural phases which represent the commitment to the funding, or the earmarking in the budget of the amount of money needed for determined expenses which establish the binding condition of the amount's destination, liquidation (determination of the exact amount of the expense or debt with the contextual selection of the exact creditor), order (issue of expense account for payment of an amount of money to creditors), and payment.

The second type concerns the funds put at the disposal of agencies or international organizations operating exclusively in the space or astronomy sector (ESO is active in particular in this sector, as well as ESA which funds scientific and application projects) or with broader scope (European Union), which includes in any case the development of technologically advanced programs in the space sector.

The programs developed by ESA, in particular, can be "mandatory" or "optional." The mandatory programs are performed in the framework of the general budget and the scientific program budget and include the basic activities of the agency (examination of future projects, technological research, common technical investments, information systems, educational programs). All of the Member States contribute financially to these programs in proportion to their national GDP.

The other programs, termed optional, involve only several Member States which are free to establish their level of financial participation to such programs on the basis of subjective evaluations. Both mandatory programs and optional programs are developed through the assignment of contracts to the industries of various ESA Member States which follow the logic of geographical return. For this reason, each country receives compensation for the investments effected for contracts for national industries of equivalent value.

The rule of geographical return which characterizes ESA, does not apply instead in the framework of the European Union, which finances space mainly through Framework Programs for Scientific and Technological Research of the EU (R&S and technological innovation) and the network of trans-European transport (Trans-EuropeanTransport Network-TEN-T).

It is important to underscore that the European Union and the European Space Agency, with the aim of optimizing the use of financial resources at the European level, unite in developing projects of common interest co-financing major programs such as, for example, the European program for satellite navigation or GMES, Global Monitoring for Environment and Security.

The third form of public funding comes from national agencies which finance the development of space programs on the basis of multiyear plans drawn up according to research and development objectives, including industrial ones, which the governments of each country aim to follow.

7.2. Private Financing

Commercial space projects, which can guarantee economic returns to their promoters, can be financed either in the framework of typical economic activities of the enterprise which develops them (corporate a) or by separating the economic initiative to be realized by normal business activities ("project financing"-type).

In the first case, the project to be realized is part of the normal business operations and the decision regarding its financing is taken on the basis of its impact on the general economic-financial equilibrium of the business which realizes the investment. In the second case, the investment decision has as its objective the economic-financial equilibrium evaluation of one specific business project, legally and economically independent from the characteristic management of the businesses which develop it.

In this chapter, we will deal with the methods of economic-financial analysis and evaluation of investment projects, specifically highlighting the distinct characteristics of satellite programs.

Since these projects normally involve the participation of individuals and companies with various competences (manufacturers, satellite operators, launch services companies, financial institutions, etc.) and are financed through the tools of "project financing," in this section we will focus mainly on those tools, emphasizing the main types of "project financing," the types of companies which participate in them in various ways, the contractual and legal structures of these operations and, in particular, the guarantee mechanisms (the so-called "security packages") normally required by financial institutions.

The chapter will conclude then with an analysis of several space projects in which "project financing" tools have been used.

7.3. "Project Financing" for Space Programs

Iridium, Globalstar, ICO, Thuraya, Sea Launch are only several of the various examples of commercial initiatives in which "project financing" tools have been applied to space programs.

Beginning in the 1980s, with the broad development of a commercial market for telecommunications, observation and launch services, "project financing" found widespread use in all satellite projects, and space in general, which could generate major economic returns for the industrial and financial sponsors involved.

Since "project financing" is a financing operation based on the ability of the company financed to reimburse financing obtained in the form of risk and debt capital, this financial instrument was applied exclusively to space projects of a commercial or primarily commercial nature.

Definition of "Project Financing"

"Project financing" can be defined as a financial operation in which:

- The economic initiative is realized by its promoters through the establishment of a project company, called the "Special Purpose Vehicle" or scope company which allows the economic and legal separation of an initiative, the "Ring Fence," the object of financing by the general activities of the companies which participate in this initiative as sponsors.
- The initiative is evaluated by financial institutions, for example, banks and shareholders, mainly on its ability to generate returns and cash flow.

- The cash flows connected to the management of the initiative represent the main source for the debt service and for the remuneration of the risk capital.
- The main guarantees in favor of the banks, or financial organizations, are mainly of a contractual nature.

"Project financing," although presenting similar characteristics to a normal business financing, i.e., corporate financing, distinguishes itself from it inasmuch as the financing decision is based on the economic-financial evaluation of a single entrepreneurial decision, separated from the general activities of the sponsors (participating parties) through the establishment of a special purpose joint venture, the previously mentioned SVP, or a project company whose business purpose is to realize a specific project of investment. Therefore, we can derive that the investment decision does not depend on the economic-financial equilibrium of the sponsors but from the profitability profile of the project.

Although it is undeniable that the evaluation of the merit of credit and therefore of the financial strength of businesses which participate as shareholders to a "project financing" project can positively influence the availability of banks towards financing an initiative, "project financing," as a financial tool, basically disregards this evaluation and therefore analyzes the single financing operation on the basis of the economic returns it expects.

With this view, however, the financing decision of banks depends in great measure on the experience and managing ability of the sponsors with respect to their financial capacity, inasmuch as it is the sponsors' capacity, and not their financial standing, which is the main guarantee for the success of the initiative that is being financed.

"Ring fencing," then, understood as the economic and legal separation of the initiative through the establishment of an ad hoc company whose business purpose is the realization of a specific initiative, represents the first element which characterizes a "project financing" operation.

The project company, normally in the form of companies with share capital, is established by sponsors in the initial phase of the initiative and generally has limited capitalization which increases in time according to the degree of development of the initiative and therefore the financial needs of the company which realizes it. The financial plan of the project company is defined according to the business plan which is defined by the founding partners and, subsequently, is arranged with the banks.

The founding partners are represented by the shareholders, for the development of his/her own *core business*, to realize the initiative and for this reason are defined as core sponsors, or industrial or strategic partners. Their participation to the financing of the initiative is evaluated not only on the basis of the profitability outlook of the project company, but also according to the industrial returns which can be derived from the realization of the project itself, both during the investment phase (construction of the work or infrastructure) and during the management phase (commercial use of the infrastructure or work financed).

In the space sector specifically, the industrial or strategic partners can be represented by manufacturing companies interested in building, through a contract to be signed with the SPV, the project's infrastructure (space segment and ground segment), by telecommunications satellite operators interested in supplying services of various nature through the infrastructure commissioned by the SPV, by

telecommunication companies in general or by companies producing stations or on-ground equipment.

As an example, the body of sponsors of the Thuraya[1] project, represented by a "turn-key" system (i.e., realized with a contract including construction, launch and putting into operation) of three fixed and mobile telecommunication satellites, was implemented through a dedicated company established in the United Arab Emirates in January 1997, and which had as shareholders Boeing Satellite Systems, the ETILASAT (Emirates Telecommunications Corporation—UAE) and various other telecommunication companies located in countries under coverage by the system, an international organization (Arabsat), and a series of financial investors such as Abu Dhabi Investment Company (ADIC), the Dubai Investments PJSC, etc. The Thuraya company was initially capitalized with about 25 M$, increased after about 1 year to about 500 M$ following the subscription of new shares by new partners.

Another example, in the launcher sector, is represented by the Sea Launch project related to the supply of launch services for geostationary satellites through a launcher lifting-off from a platform located in the Pacific Ocean. This initiative was realized through an international "Joint Venture" formed in 1995 between Boeing Commercial Space which had the responsibility for operational management and commercialization of services, the Russian aerospace company RSC Energia, the Norwegian Kvaerner, now Aker Solutions, responsible for building the Odissey platform and the Ukrainian Yuzhnoye/Yuzhmash, supplier of the first two stages of the ex-military Zenith 3SL rocket. The investment in share capital of the industrial partners was increased in time through the addition of other financial commitments by several of them (subordinated loan and guarantees in favor of the banks), as well as major financing by the international bank system in part guaranteed by direct commitments by the sponsors.

As indicated, in the case of industrial initiatives with a good financial return outlook, even financial sponsors who do not have an industrial interest in the initiative but who participate with a view of pure financial return can participate to the financing. These legal entities, normally represented by investment companies or venture capital, usually acquire a minor participation in the project company in its initial development phase and then subsequently disband to receive a "capital gain."

Financing Sources

In "project financing" operations, it is possible to select various categories of financing sources, equity capital, funds which can be assimilated to equity capital and debt capital, classified according to their degree of priority with which they are reimbursed, the level called "seniority," should, in particular, the company project fail or be liquidated.

The equity capital, or risk capital, represents the share capital with which the company project is provided, in predominant measure, by the promoters of the initiative (sponsor or strategic investors) through the subscription of shares or stakes in the company.

[1] Thuraya is a private company, based in the United Arab Emirates, which supplies telecommunication satellite services.

The equity capital can be supplied even by different entities than the promoters, i.e., the "financial investor," in the logic, as stated, of pure financial investment, but this supply is always minor with respect to that of the strategic sponsors.

The share capital can be represented by various classes of shares (common stock, preferred stock, etc.) to which different rights on the part of the subscribers are linked. The share capital is deposited when work has progressed, therefore in the manufacturing phase of the work, or when determined planned and/or unforeseen events have occurred during the commercial management phase of the initiative.

Satellite projects developed in the last years have presented a rather high financial "leverage."[2] The companies' capitalization level is, however, determined according to the risk profile of the single initiative,[3] which in turn depends, among other things, on the "commitment" level, the commitments to acquire the SPV services, which are subscribed by potential customers of the SPV with the SPV, from technical and technological risks of the project.

The funds which can be assimilated to share capital, generally called "quasi-equity," are instead hybrid financing instruments which have typical characteristics of both risk capital and debt capital. Subordinated loans, mezzanine debt, convertible bonds and in general all forms of financing which are preferred in reimbursement with respect to risk capital but deferred with respect to ordinary and preferred debt fall into this category.

The use of "quasi-equity" has the aim of reducing the average weighted cost of capital, since this financial instrument involves a lesser cost with respect to risk capital (even if it is higher with respect to debt capital), does not attribute full rights to vote and allows increasing the "leverage" of the project.

Debt capital, called "senior debt," is made up of bank loans which contracted by the SPV, loans which have reimbursement priority with respect to all other forms of financing of the project, concerning both the reimbursement of the capital and the payment of interest. In other terms, it can be said that the "cash flow," generated by the project company can be used first for loan reimbursement, then for "quasi-entity" reimbursement and only in a residual way for the payment of dividends which represent the return expected by the shareholders on the risk capital deposited.

Even the debt capital, like the share capital, is provided by the banks to the project company on the basis of the work progress status to a financial plan previously evaluated and accepted by the financers. The satellite programs normally see the use, in the initial phase of the initiative, of risk capital brought by the industrial partners as a source of financing of the project for covering nonrecurrent costs (research and development, pre-investment costs, studies, etc.) and, in subsequent phases, to the use of debt capital, which is supplied in parts in line with the investment plan of the project company.

[2] Relationship between risk capital (Equity) and debit capital (Debt).

[3] As an example, we can cite the financing of the New Dawn Satellite Company Ltd., formed by Intelsat and a South African investment company, Convergence Partners, whose overall investment value (about 240 M$) wasfinanced for about 40 M$ through risk capital brought by the partners and for the rest through bank financing of Nedbank Capital and Industrial Development Corporation of South Africa.

Debt capital, because of the minor risks of the reimbursement priority compared to other forms of financing, clearly has a lower cost compared to risk capital and "quasi-entity," and consequently a high financial leverage with a reduction of the average weighted cost of capital of the initiative.

The debt capital can have different forms, substantially summarized in banking financing at short-, medium, and long-term, in bond loans and leasing.

In satellite projects all three financing instruments can be present, even in combination with each other, with a mix and timing which depend on the financial plan of the SPV and from the type of investments which must be realized.

The Economic-Financial Analysis of Space Programs

The proper economic-financial analysis of a project starts from the selection of the three macro-phases that characterize it: construction of the infrastructure, final/acceptance testing of the infrastructure, commercial management.

The construction phase occurs when the investment is realized; the so-called Capex or "Capital Expenditure" and therefore the financing in risk or debt capital by financers are supplied to the SPV. In this phase, the financing is supplied at the work progress status; therefore, the exposure of the financers increases according to the development of the infrastructure and reaches its maximum peak at the time prior to the testing/acceptance phase of the infrastructure. The initial phase of the project is precisely the construction of the infrastructure in which the SPV has outbound financial flows called "cash out," represented by inbound investment costs and flows represented by the supply of "equity" financing (subscription of shares) and debt (supply of financing). In this phase, the SPV does not generate profits and cash flows; therefore, it can neither distribute dividends to shareholders nor can it pay interest on the loans supplied, interest which, for this reason, is capitalized and is therefore to be added to the financed capital, thereby determining the overall amount of the debt to be reimbursed.

The second phase is represented by the testing of the infrastructure, which clearly foresees a series of tests defined contractually which, if passed, determine the final acceptance of the infrastructure, the payment of the balance to the constructor, and the start-up of a period of guarantee whose duration depends on the type of project and therefore on the type of infrastructure. The testing phase is clearly the most critical for financers, inasmuch as all financing is supplied but there is no certainty that the infrastructure will pass the final tests and therefore that the commercial phase can be started up. In the testing phase, the outbound flows are represented by final payments to the constructor and by the functional expenses of the facilities, while inbound flows, called "cash-in" are generally still absent at least if, as highlighted, the company does not already provide the so-called "interim services."

The third phase of the project is management, in which the SPV provides services and therefore generates profits and inbound cash flows, the "cash-in." In this phase the company no longer has investment costs inasmuch as the infrastructure has been completed; however, the cash-out is generated by the company's operation costs.

In a satellite project, the three phases described above can be graphically represented as given in Figure 7.1.

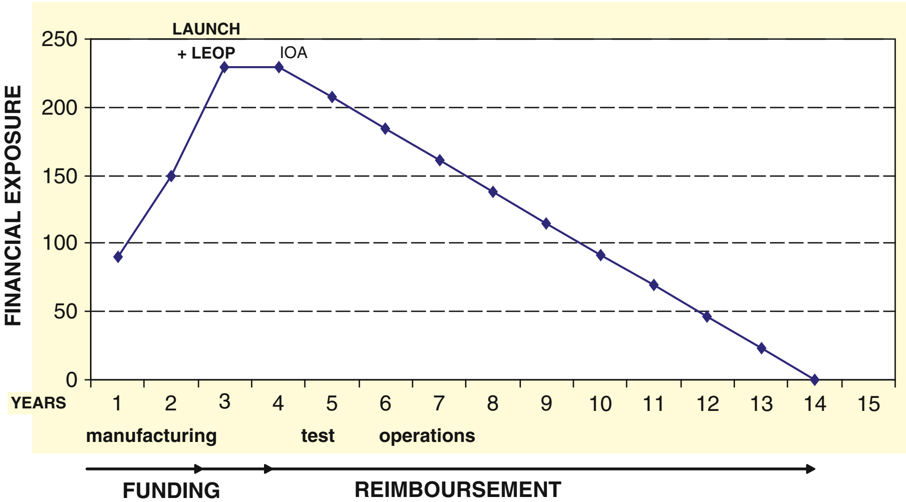

Figure 7.1. Phases of a "project financing" operation for a satellite project.

The investment phase includes the construction of the satellite, the launch campaign and the LEOP, "Low Earth Orbit Operations" phase; the testing phase involves the "commissioning" activities of the satellite and the control center and ends with the "In-Orbit," "Acceptance" or "System Acceptance Review," while the management phase begins with the providing of services and ends when the satellite completes its own operation lifecycle.

Sometimes, in space projects, these phases can partially overlap. For this reason an SPV might begin the commercial phase and therefore start generating returns/flows of cash before the investment/construction phase has been completed. This occurs in particular in satellite programs in which "time-to-market," the SPV's entrance into the market, represents the main critical factor of success and it is therefore necessary to anticipate this phase as much as possible. In these cases, the SPV, in order to ensure market shares or to capture determined customers, starts up the commercial phase, "interim service," using nonproprietary satellites (a typical example is the leasing of transponders from existing operators) so that it can complete the construction phase and start up service through the satellite infrastructure with a good customer base. The construction phase and the management phase can also overlap when there is a modular-type project, as for example a constellation of satellites which are manufactured launched and tested in orbit in consecutive phases, and therefore, begin commercial operations (operational phase) at different times.

Risk Analysis

Risk analysis is an essential aspect for the development of a "project financing" operation and is closely related to the above-mentioned guarantee aspect.

In general terms, the risk must be determined and evaluated in terms of impact on the initiative, eliminated or mitigated, transferred or accepted; in the latter case it will

be necessary to evaluate adequately the financial impact related to the possible manifestation of risk and therefore provide for necessary reserves.

The division of residual risks mainly involves the strategic partners of the initiative (for example, the guarantee of the satellite's completion will involve the manufacturing company while the commercialization of the service at determined prices independently from the economic progress of the market will concern the satellite operator) who will accept the risks according to their ability to manage them, and especially, the economic return of the activity connected to the assumption of the risk itself.

A proper division of the risks is essential for the success of an operation of "project financing" inasmuch as it confers stability and equilibrium to the latter and, definitely, ensures the technical-economic and financial feasibility and consequently bankability.

The concept of financial feasibility is a "project financing" operation which coincides with bankability; a project can be defined as "bankable" when the risks associated with it are for the most part acceptable to banks considering the financial return deriving from the financial operation, a return which is considered lower to the one expected by shareholders because they bear risks which are higher compared to banks, and as a result, expect a higher return on investment; the ROE, "Return on Equity" is in fact higher to the expected return from a bank on a finance operation, a return made up of the interest, commissions and costs related to the loan.

It is therefore worthwhile to point out that, even with a high financial return on the operation (high interest rate on the loan, high commissions, etc.) banks will not accept running risks which are not efficient for their business and will ask the sponsors/shareholders for various kinds of guarantees; however, they will all be aimed at ensuring the proper implementation of the project as well as to partially recovering the loans provided. Regarding this, it should be emphasized that the problem of the guarantees is so important in "project financing" operations that, precisely on the basis of the guarantees, we can define two macro-categories of financing, "without recourse" and "limited recourse."

The definition of "project financing" "without recourse," without recourse on the sponsors, indicates a financing operation in which the bankability of the project is based solely on the ability of the project to generate cash flows in such a way as to guarantee the servicing of the debt, i.e., the reimbursement of the bank loan and on the value of the "assets" of the project company. However, it is rarely applied and in reality all "project financing" operations are of "limited recourse," with limited recourse on the sponsors and therefore foresee the obligations by the sponsors, c.d. "second-line guarantees" which together with cash flow expected from the initiative and contractual guarantees which will be dealt with afterwards, are a necessary condition for the bankability of an initiative.

This involves limited recourse because the guarantees do not cover the entire value of financing (capital plus interest) but only a part of them, implying the direct assumption of commercial risks by the banks.

Second-line guarantees are mainly financial in nature and are made up of, for example, the commitment by the sponsors to deposit added share capital should investment costs increase or management of the company (and/or deterioration of several indices of financial coverage or profitability of the project company), from the

commitment to inject liquidity in the project company to satisfy the need for circulating capital and other needs.

Sometimes, especially during the first phase of commercial management of the initiative, the sponsors can also be required to counter-guarantee the bonds of a commercial counterpart, and in this case, the guarantee can be made up of the commitment to buy at determined prices and determined quantities of products or services of the project company.

The second-line guarantees can take on various forms, but as wide-ranging as they may be, they cannot be substituted by contractual guarantees which in any case represent the cornerstone of a "project financing" operation.

The contractual guarantees involve legal bonds subscribed by the participating entities to an initiative to guarantee the respect of the underlying assumptions of the SPV's "business plan" and therefore to reduce its economic-financial volatility.

Therefore, the contractual guarantees impact the cost and profit components of the initiative and its profitability. The contractual guarantees are represented, in particular, regarding costs, by the manufacturing contracts, the "turn-key contract," or on those from the returns on the cession contracts from products/services.

In addition to these essential contracts, there are those of a strictly financial nature, such as the financing agreement, the guarantees on project assets, and in a more general way, the overall legal/contractual documentation of the project which, in order to ensure the success of the operation, it is crucial that it be consistent, harmonized, and in particular, balanced in the division of risks among the various parties involved in the development of the initiative.

Contractual Aspects

In a satellite project, the principal contracts can be schematized as follows in Figure 7.2.

(a) The contract for supplying an in-orbit satellite system, IOD "In-orbit-delivery contract" IODs and ground infrastructure (the "ground segment" and if provided for, the "network control centers" and "local gateways"):

It is stipulated in most cases directly between the project company and satellite manufacturing company; it is a "firm fixed price contract" which provides for the in-orbit satellite supply fully tested and functioning and therefore includes LEOP—"Launch and Early Orbit Phase" services—the control activities of the satellite after separation from the launcher and up to positioning in final orbit, and the "commissioning" and IOT, "in-orbit testing."

Payments are made to the WPS, Works Progress Status, according to a detailed plan of key steps, invoicing and payment.

In most cases the contract provides for, in addition to penalty mechanisms for delayed delivery which foresees as a last resort the possible unilateral "termination" should there be serious contractual nonfulfillments by the supplier, including a mechanism of penalties related to malfunctioning in orbit of the satellite and/or ground infrastructure.

This mechanism foresees that a determined percentage of the price (in general between 5% and 20%) is returned to the supplier, the "contractor," only if the space

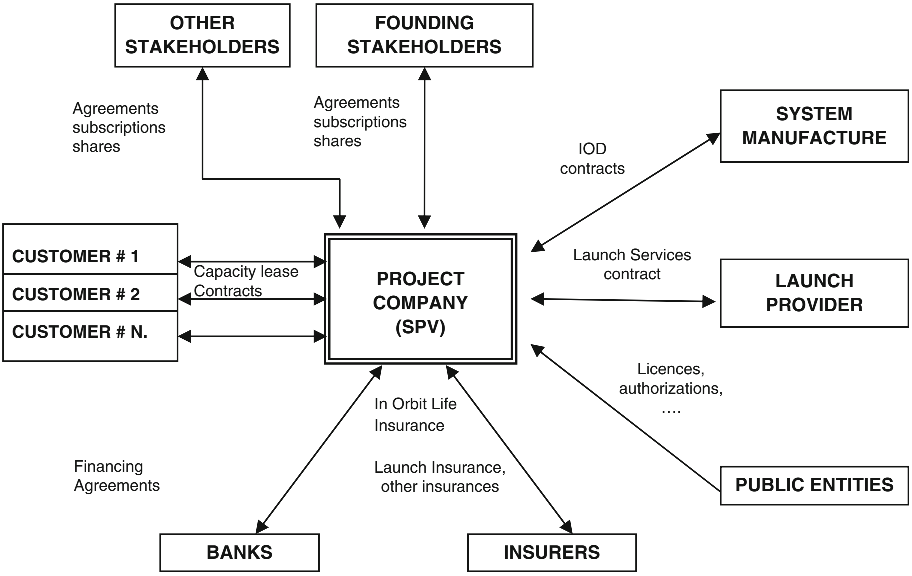

Figure 7.2. Contractual schema of a "project financing" operation for a satellite project.

system, satellite and control center are in compliance with technical specifications and therefore perfectly functioning at the end of the LEOP, In-Orbit Commissioning and Testing phase.

Should this not occur, the contract foresees the application of penalties (nonpayment of part of the price) of an increasing amount according to the seriousness of the anomalies found. In some cases it is also foreseen that the share payment of the supplier be spread out over a variable period, in general, between 3 and 7 years, and that it can be withheld from the SPV in the case of the in-orbit malfunctioning of the satellite which appear in the subsequent years of in-orbit acceptance of the satellite.

For IOD contracts, after the final acceptance of the system, a period of guarantee is always foreseen at least 1 year for the ground infrastructure, as well as the obligation on the part of the supplier to perform at his expense all the activities to correct possible malfunctioning of the satellite.

In addition, other obligations assumed by the supplier include the supply of all equipment, data, documentation and software for managing the systems, the retrieval of all licenses, authorizations and import–export permits and, generally, all activities aimed at coordinating the orbital position and frequencies with the ITU, the "International Communication Union."

Finally, customer support in the choice of launch service provider, negotiation of the relative contract and sometimes the negotiation of insurance contracts, "Launch-Insurance and In-Orbit Insurance" can enter into the scope of the contract.

(b) Supply of launch service contract, LSC "Launch Services Contract":

It is generally stipulated by the SPV with a "Launch Service Provider" an LSP such as Arianespace, Sea-Launch, the ILS and directly financed by it.

The management of the contract is normally done directly with the contractor who can also manage relative payments, which are also made at work progress status.

The LSC, also at firm and fixed price, defines in detail the activities which are the responsibility of the LSP (obtaining necessary licenses and authorizations from local authorities, effecting the launch according to agreed launch windows, possible re-launch of the satellite in case of failure or breakdown of the launcher, etc.) and those which are the contractor's responsibility (obtaining authorization from the authorities of his/her country, transport of the satellite to the launch site, preparation of the satellite for launch, post-launch satellite management).

The contract obviously defines the timeframe windows of the launch and the reciprocal commitments should there be delays for having the satellite ready by the contractor or the delay of the launch for reasons which could be attributed to the launcher. Precisely define the LSP provider's obligations in case of launch failure and envisages, as does any service contract, the penalty system of the LSP for nonfulfillment, the causes of withdrawal, force majeure, transfer of risks, etc.

It is worth noting that sometimes the supply of launch service is an integral part of the obligations foreseen in the above IOD contract; in this case the LSC will be a subcontract stipulated between the contract and the LSP.

(c) Insurance contracts the "Pre-launch Insurance," "Launch and In-Orbit-Insurance," "In-Orbit-Incentives Insurance," "and political risk insurance" etc.):

Represent one of the main aspects of contract structure which characterizes a "project financing" operation in the space sector.

They can represent, on the whole, the third cost item of a satellite project; their contents vary according to the risks covered, their value and their duration.

With the exception of the "pre-Launch" policy, which has rather standard features (ensures the satellite against damages which can occur to it during the transport phase and during activities at the launch site up to the starting of the launcher's motors), the "Launch and In-Orbit Insurance" and the "In-Orbit-Incentives Insurance," or the "In-Orbit Life Insurance" vary significantly according to the risks actually insured of the exclusions, exemptions, deductibles, etc.

If we wish to schematize these coverages we can state with several simplifications that the "Launch and In-Orbit-Insurance" insures the satellite against risks of total and partial loss for reasons due to partial or total breakdown of the launcher (including the positioning in an improper transfer orbit) and/or problems which occurred during the LEOP phase, Commissioning and IOT, while the "In-Orbit-Incentives Insurance" insures the risks of total or partial malfunction which could occur to the satellite after the IOT phase.

The duration of this policy depends on the insurance market's ability at the time of risk classification, in general, their duration is around 3–5 years; the values to be insured are determined on the basis of rebuilding the satellite, the launch and related insurance.

The process of insuring a satellite is extremely complex and typically begins with the selection by the manufacturer or the SPV of an insurance broker who presents to the potential subscribers, the "underwriters," a report containing information of a technical, contractual, and economic nature on the operation; the "underwriters" conduct an in-depth analysis to evaluate the risk to be insured (reliability of the satellite and launcher, orbit location of the satellite, etc.) and present offers containing the conditions and terms of the insurance coverage to the broker.

The economic conditions offered depend not only on the "risk analysis" of the specific operation, but also on the ability of the insurance market, which is related inversely to the premium level. When the economic conditions are generally favorable, the insurance company has in general good economic-financial performance and can offer high insurance capacity and levels of appropriate premium levels, the exact contrary is demonstrated in general adverse economic conditions, in which there can be impacts on the company's business plan for the project company which are quite significant and which can sometimes alter the profit profile of the initiative.

The insurance process proceeds with the presentation of offer to the customer, the selection of what best responds to his needs, the stipulation of the insurance contract and the payment of the premium which is a necessary condition for the policy to enter into effect.

In addition to the above-mentioned insurances, there are also those against political and commercial risk, those of civil responsibility vs. third parties, "Third Party Space Liability," coverage against damage to property, "Property Damage" and "Business Interruption" and generic business policies, Directors and Officers, General Liability.

(d) Contracts for service provision ("capacity lease agreements," "imagery services contracts," etc.):

They are stipulated between the SPV and its customers, who can be "wholesale" customers, regional or local operators who buy wholesale, or "retail" customers, final users of services, according to the business or distribution model of the project company.

In the satellite programs financed on the basis of "project-finance" it is important that such contracts are of multiyear duration that they are stipulated with reliable counterparts from the commercial and financial viewpoint that they absorb in good part the operational capability of the satellite, that they are already started up, at least with main customers, at the time of start-up of operations of the system.

In addition to the multiyear contracts there are temporary contracts which foresee, for example, the allocation of "on-demand" capacities for digital video broadcasting, or the provision of satellite images related to specific requirements (a typical example is that of images taken during crisis situations, floods, earthquakes, nuclear accidents, etc.).

From the banks' viewpoint, it is important that such contracts are preceded by "letters of interest" on the part of potential customers, and that the project company begins to provide several services before the start-up of the system's operation using other satellites (cd. "interim system services") so as to capture and to loyalize a potential customer.

It is important to underscore that the ownership of rights originating from the contracts under examination, as well as those deriving from other contracts concerning the project, are in general transferable from the project company to the financial institutions on the basis of clauses contained in the contracts and financing agreements.

(e) Financing contracts:

The contents of these contracts vary according to the type of financing which is agreed upon with the project company.

The financing structured in the framework of an operation of "project financing" can take on different forms, often present contemporaneously in a same project.

As evidenced above, financing can be in the form of bank bonds, exportation, leasing and co-financing, direct financing by the system supplier—“vendor financing.”

The relative contracts are in general very complicated and cannot be described in detail in this book; in any case, their basic elements are: the financial amount, their destination, the guarantees, interest rate, commissions, means and period for payment and reimbursement, suspending conditions for the effectiveness of the financing, financial obligations to be maintained, etc. Financing contracts are clearly regulated by the company’s business plan and are directly stipulated by the project company or by the companies controlled by it, with its financers.

In addition to the above identified contracts which however do not complete the contractual structure of a satellite “project financing,” there are the government authorizes and permits which are required for the manufacture, launch and management of the satellite and its related ground infrastructure.

The most significant part of these authorizations is made up of the licenses and related agreements to orbital position and the relative spectrum of frequencies. In addition to these authorizations are the licenses for the deployment and management of the gateways and fixed and mobile terminals (where present) which are in general the responsibility of local operators, but which represent, in any case, one of the main critical factors of success of the initiatives which are the object financing and are therefore carefully evaluated by financers because of their impact on possible delays in obtaining authorizations that can cause on the profit profile of the initiative.

Analysis of the “Business Plan” for Space Programs

The “business plan” is the cornerstone of any financial operation of the project. It involves an information document, which describes the project to potential investors and financers—whether they are bringing risk or debt capital—from the qualitative and quantitative points of view.

The “business plan” contains all the elements relevant to the purposes of the investment decision, such as:

- The aim of the project
- The sponsors and their roles
- Market analysis
- Technical and technological aspects
- Regulatory, contractual and legal aspects
- Company structure of the SPV and “corporate governance” regulations
- Risk factors
- Economic-finance plan

The first draft of the business plan is done by the strategic sponsors of the initiative and has the objective of defining the project idea, qualifying the main elements and quantifying as a first step its economic range.

The business plan is then subject to elaborations and subsequent refinements which reflect the level of detail of the analyses performed and, in almost all cases, the analyses and considerations done by the consulting company which, usually, are

the responsibility of the sponsors (or the SPV directly) to refine the business plan and validate it before presenting it to potential investors.

The first difficulty we encounter in the elaboration of the business plan involves quantifying the overall demand for services/products, which will be offered by the project company and in determining the market share to be reached on the basis of the sales price of the product/service offered.

The difficulty of carrying out a proper analysis of demand is directly proportional to the level of innovation of the service and the product offered, and therefore, the availability or not of information and qualitative and quantitative data which allow performing a "benchmarking" between the "business plan" of the specific initiative and that of similar projects.

It should be stated, however, that even in the case of projects which are based on technologies, services and/or products which do not present particular characteristics in terms of innovation, the analysis of demand and evaluations of competitive positioning of the project company represent without doubt one of the most difficult, if perhaps the most difficult to analyze in the "business plan."

For this reason, it is a standard practice for the sponsors of the initiative to confer with a consulting company specialized in analyzing in detail the "business plans" of initiatives and therefore validating it in the eyes of potential financers; obviously this validation will be useful only in the case the consulting company has a specific knowledge of the reference market and of the commercial dynamics related to the initiative which is the object of financing.

Since the causes of failure of "project financing" operations are for the most part the result (see the example of Globalstar and Iridium) of a mistaken analysis of demand, also meaning a mistaken evaluation of "pricing" to be applied to the product/service offered, the financers of the initiative will have to pay close attention to this aspect and will therefore carefully subject the economic-financial model of the project to a "sensitivity analysis" which will basically measure the variations of the profitability indicators of the initiative, in particular, the IRR "Internal Rate of Return," according to the different cost parameters (increase of investment and operational costs of the SPV) and profit (increase/decrease of sales considering different market scenarios and/or "pricing" of the product/service offered by the SPV).

A second essential aspect of the "business plan" refers to the technical and technological aspects of the project which must be analyzed with the aim of demonstrating technical feasibility, first of all, of the initiative and, where present, the related technical risks clearly.

Even in this case, the greater the degree of technical complexity of the project, the lesser the degree of satisfaction of the initiative on the part of financers. This is because a high degree of technical complexity of the project is usually associated with the risk of cost overruns or the prolonging of realization time of the project which can also impact in a determining way on the profit profile of the initiative.

It is therefore appropriate to base the project on technical solutions which limit or even cancel out risks of delay in the realization time of the work, or of extra costs or even malfunctioning of the infrastructure through which the service will be provided by the project company.

It is evident that this aspect assumes essential importance in the case of projects in the space sector where improper technical and technological choices, not being able to be modified in the manufacturing phase, can determine the failure of the initiative.

Another essential point to be considered is without doubt represented by the sponsor team, their level of experience in developing analogous initiatives or similar to the investment objective, and from the level of financial participation in the initiative that obviously determines the level of financial risk assumed by the sponsors and therefore their "commitment" to the initiative.

We begin with the assumption that a "project financing" operation usually has important economic scope and requires participation by entities which have different competences and often conflicting interests that must necessarily find a point of balance to allow the proper management of the project.

For example, let us examine the case of a satellite project which has among its sponsors a space manufacturing company and a satellite operator. The interests of these entities will necessarily diverge because the manufacturer will try to maximize its own economic return in the industrial implementation phase of the initiative, while the satellite operator will try to reduce costs and development time of the infrastructure to maximize return on investment, a return which will in any case be evaluated according to a long-term period related to the commercial operation of the system, which in and of itself, is a logic which is far removed from a manufacturer.

It is nevertheless essential that the entities with the necessary competences to develop the initiative are part of the sponsor team and participate effectively to the financing of the initiative.

Another important element to analyze is represented by the regulatory and legal aspects, inasmuch as they can greatly impact the development time of the initiative and sometimes prevent the success of the programs.

For example, the import–export problems related to satellite programs which use materials subject to EAR or ITAR regulations of the USA, or regulatory problems both at an international level (ITU) and at a national level related to the allocation and use of frequencies, or to permit required for the deployment of ground infrastructures necessary for supplying services in the framework of telecommunication or satellite navigation programs.

All these aspects will have to be clearly analyzed and evaluated especially concerning the impact they can have on the time of development of the initiative, an essential aspect, especially for commercial-type initiatives where the "time to market" of the service offered is a critical factor for the initiative's success.

Moreover, it will be important to describe the contractual structure of the initiative, starting from the supply of the infrastructure (what is being supplied, price schedule, penalty system, guarantees, etc.) which will have to provide adequate security to financers, to banks in particular, regarding the costs and times of development of the infrastructure, to arrive to those related to concession contracts of the services will have to be, where possible, finalized, at least partially, in relation to the subscription to financing agreements.

Finally, as part of the evaluation of contractual and legal aspects of the initiative is the "security package," or the contractual and real system of guarantee of various types which is structured in the framework of the financial operations of the project it represents, de-facto, the only instrument for mitigating the risks associated with the project.

Example of a "Business Case"

The business case which will be examined as an example is represented by the planning, construction, and management of a satellite system for broadband communication services with multi-spot coverage over Europe, Africa, and the Middle East.

The financing of the project occurs on a "project-finance" base, with contributions therefore of risk capital by sponsors/shareholders of the project company and bank financing.

The value of the initiative amounts to 300 million euro and includes costs for realizing the infrastructure (space and ground segment, described as follows), the launch service and insurance premiums, project development costs, preoperational expenses, and interests matured during the construction period.

The value of the initiative does not include development costs (construction and installation) of the ground network which the "business plan" foresees as being the responsibility of local operators.

For realizing the project its promoters have established a vehicle company, an SPV called SAT-Pro, which will receive the necessary financing to cover the needs specified above and will stipulate active and passive contracts described as follows.

The SAT-Pro System

The system is made up of two main segments: space and ground.

The space segment, the property of the SPV, is represented by a geostationary satellite for telecommunications and by a ground control center (NCC "Network Control Center") with control functions of the satellite and allocation of its transmitting capability to the telecommunications operators.

The ground segment includes the stations, "gateways," needed for managing and controlling the network of operators and fixed and mobile terminals of telecommunications linked with this network.

The "business plan" assumes that the ground segment will be developed by a network of regional operators, who, located in the various countries covered by the service, will stipulate multiyear service contracts with the SPV.

The business plan therefore foresees that these operators have the property and therefore finance the making of the ground stations and distribute the fixed and mobile telecommunication terminals, the "end-user terminals" to the final users.

The costs related to the development of the ground segment are therefore not considered in the business case described as follows.

The SPV Project Company

The project company, called SAT-Pro, is located in Alfa country, where it can benefit from a favorable fiscal policy.

Its shareholders of reference, or strategic sponsors, are the Sat-Manufacturing S.A., a major manufacturing company of satellites which will develop and build on the behalf of SPV the space segment, the Gat-Manufacturing Ltd., the producer company of gateways and user-terminals which will provide the ground segment necessary for supplying telecommunication services via satellite, two regional operators of telecommunications, Sat-Service X and Sat-Service Y, which will have, respectively, exclusive distributing rights of telecommunication services to the SAT-Pro in several countries covered by the service.

With a total investment cost of 330 million euro, the strategic sponsors have committed themselves to financing the Sat-Pro, with risk capital, “equity” up to 100 million euro, the remaining share of investment is expected to be financed for 200 million euro with bank financing “debt” and for the remaining share of 30 million euro through financing for the research and development provided by several institutional agencies.

The “debt/equity” relationship therefore presents a high financial leverage.

The Investment

The total costs of financing amount to 330 million euro and include:

	Cost (in millions of €)
Satellite	147
Control center (NCC)	54
Launch service	82
Insurance policies	37
LEOP + commissioning	10
Total cost of the project	330

The investment period (construction phase) is 2 years, the management period (commercialization of the service), even if the life cycle of the satellite is estimated to be 15 years, it is prudent to determine it in 13 years to take into account possible deterioration in the transmitting capabilities of the satellite during the final phase of its operational life cycle.

Given the type of investment realized a start-up phase is not foreseen. In fact, once it has been completed, launched and tested in orbit it is expected that the satellite will operate at 100% of its transmission capability.

The time management plan of the construction activity and system launch is indicated in the following figure (Figure 7.3).

Returns

The returns from the SPV are estimated assuming that the provision of services occurs in three different geographical areas, in which there is expected to be an increase in demand, with a tendency to saturate the transmitting capability of the satellite already at the end of the fourth year of commercialization of the service.

Beginning in the fifth year, the returns are expected to be stable because of this saturation, while increase in demand for the services offered is expected to increase and therefore offer wide margins of security with respect to the expected level of returns.

The return hypotheses assume a market penetration by the SPV in the order of 30% of overall potential demand expected in the three geographical areas of service coverage, according to the category of users.

The overall demand has been evaluated through specific market studies “primary research,” commissioned especially by the SPV, a primary consulting firm.

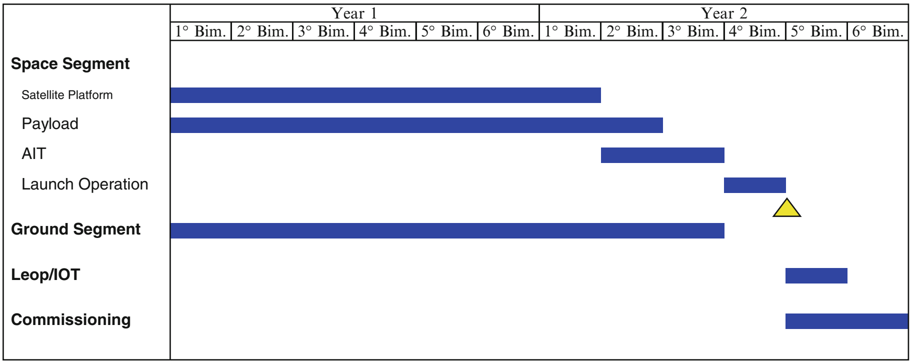

Figure 7.3. Implementation phases of the SAT-Pro system.

The returns of the first year of commercial operation (or the third year of the plan) are equal to 50% of those of the second year of operations inasmuch as the service is provided beginning in the second semester.

The business model of the SPV assumes that the SPV will operate as a "wholesale" supplier and will see its transmitting capability to regional service providers who in turn will offer fixed and mobile telecommunication services to final users; the SPV is therefore not involved in providing "retail"-based services—offers directly made to final users.

Operational Costs

The operational costs of the SPV are divided into seven items identified below:

- Human resources
- Maintenance
- Marketing and sales
- Royalties
- Insurance policies
- Outsourcing services
- Other costs

Human resources costs include both those for direct human resources and indirect human resources. They increase 2% per year and include social security and fiscal requirements.

There are no staff costs during the investment/construction phase of the project because the "business plan" assumes that in this phase the SPV will use staff provided by the sponsor with relative costs taken on by the sponsors themselves.

Maintenance costs are related to maintenance services to the NCC, to the updating of the software, to the maintenance of offices and general facilities.

The maintenance costs of the NCC are calculated parametrically according to the value of the NCC itself.

The maintenance costs increase by 3% each year in line with the average increases registered in companies operating in the same sector.

Marketing and sales costs are calculated as 5% of returns, including distribution, advertising and promotional activities costs; the marketing and sales cost value is contained in consideration of the business model of the company, based as we have stated on the providing of services to service providers and not to "retail" customers.

"Royalties" includes amounts that the Sat-Pro has committed to pay public institutions which it is expected will provide financing to cover several nonrecurring costs—research and development—of the satellite.

The "royalties" are calculated as a percentage of returns which the project company will develop in the planned period (15 years).

Insurance costs mainly concern the insurance of the satellite against risks related to the launcher, "Launch Insurance," and to LEOP activities, until the positioning of the satellite in the definitive orbit.

These costs are to be considered as investment item and therefore are presented in the table as source use under "Insurance."

The insurance premiums for this coverage have been estimated according to the value of rebuilding the satellite, the cost of a new launch and the value of the corresponding insurance premium.

The insurance costs which have instead been presented in the table of economic account refer to civil responsibility policies for damage to the control center, for political risk and general risks related to the company's business. They amount to 3 million euro the first year of operation for the service and increase by 1% each year.

The SAT-Pro business plan does not provide for insurance coverage for possible performance deterioration of the satellite during its operational life.

The costs for outsourcing services are estimated at around 3 million euro per year.

The "other expenses" item includes other possible operating expenses which will have to be supported by the project company. A 2% increase per year is also expected for this item.

Amortization costs of investment are established at about 8% per year. It is expected therefore that the investment, from an economic point of view, will be covered for 13 years.

The fiscal charge is equal to 35% of profits and does not vary during the life of the project.

Financial charges and proceeds are calculated, respectively, at an annual interest rate, respectively, 5% and 3%.

Economic-Financial Model

The economic-financial model is essentially made up of:

- A Sources and Uses of Funds table which highlights the requirements for funds for realizing the infrastructure, the CAPEX "Capital Expenditures" and different sources from which we can acquire financing.
- An Economic-Account table which juxtaposes costs and returns according to the administrative period and thus illustrates the economic result of the management in the planning years. The economic account in particular points out all the factors which have contributed to the management cycle and allows finding the partial results of all management phases in which the company's activities can be broken down.

- An Assets and Liabilities table which provides a picture of the assets and liabilities of the business at any given moment, comparing assets and liabilities. By using this table we can see what are the sources of financing and the investments carried out by the business.
- A "Cash Flow" table which presents the amount of financial availability which is generated in the company in a determined period of time. This corresponds to the balance between current incomes (business income) the current outlays (costs di competence for the period) which have generated a financial disbursement. In analyzing the investments, the cash flow table indicates all the entries (income) and outlays (disbursements) which are generated during the operating life of the project. A recapitulation table of the economic-financial model results which include two categories of indicators: profitability investment and financial coverage of the project.

Indices of profitability are shown as the IRR which corresponds to the interest rate which makes null the algebraic sum of cash flows actualized by the project and the "Net Present Value" (NPV) which is the algebraic sum of the project cash flows actualized as a rate equal to the opportunity cost of capital, the "cut-off rate."

The IRR and the NPV are indicators which are calculated to verify the convenience on the part of promoters of realizing the project. They therefore emphasize the ability of the project to create wealth and only indirectly express the capability of the project to reimburse and remunerate debt capital.

Debt capital, an important aspect, can be evaluated instead through the indices of debt coverage which represent in particular for the banks an essential element of evaluation for the viability of an initiative.

The main indices of coverage are the Pcr "Project cover ratio," which expresses the relationship between the current net value of cash flows over the life of the project and the current debt value; the Adscr "Annual debt service cover ratio" which measures the ratio between cash flow of the project (net of taxes) for a given year and the service of total debt of the year; and the Lldscr "Loan life debt service cover ratio" which measures the ratio between the current net value of cash flows for the duration of the financing and the debt value at the beginning of the actualization period.

The financial analysis based on these hypotheses highlights a return on investment IRR equal to about 28% which much be higher than the profitability profile of the initiative with the same characteristics in the same sector.

The analysis shows that an initiative characterized by a good profitability profile and significant cash flows already beginning in the fourth or fifth years, a circumstance which allows shareholders to minimize recover time for capital invested, the "pay-back period" and therefore to contain, given the overall profitability of the initiative, the riskiness of the project from the timing point of view.

The "leverage" degree of the project is rather low, even because of the public contributions covering in part the costs of research and development.

The indices of debt coverage offer high security margins in consideration of the "cash flow" expected and rather the limited financial leverage.

In the evaluation of a "business plan" the analysis of the above-described tables is absolutely essential.

They, in fact, quantify along the temporal horizon of planning the project the profitability expected on investment, financial requirement of the initiative and sources of financing for it which has been seen previously can be mainly grouped into two risk capital categories, “equity,” brought by the project sponsor and the debt capital, mainly presented by bank financing structured according to expected cash flows of the project.

Obviously the model is based on assumptions which must be verified by the main players of the project and possibly adapted to new scenarios of project reference that should develop in the initiative. It is therefore essential not only because it reflects the project situation in its initial configuration but also because it synthesizes the contractual structure of the project and the interest of the various parties involved in it in a dynamic way and therefore changes according to new market, financial and contractual scenarios which might come into play in the structuring phase of the project (Figures. 7.4, 7.5, 7.6, 7.7, and 7.8).

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YEAR	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**tot.**
Satellite	80.00	67.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	147.00
Launch + Leop / Commissioning	0.00	92.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	92.00
Insurance	0.00	37.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	37.00
SPACE SEGMENT	80.00	196.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	276.00
GROUND SEGMENT	24.00	30.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	54.00
INTANGIBLES	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL FIXED ASSETS	104.00	226.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	330.00
PRE-OPERATIONAL EXPENSES	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL FINANCIAL REQUIREMENTS	104.00	226.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	330.00
Long Term Debt	24.00	176.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	200.00
Equity + R&D Funding	80.00	50.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	130.00
TOTAL SOURCES	104.00	226.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	330.00

Figure 7.4. Table sources-use.

YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Revenues	0.00	0.00	51.00	110.16	123.55	138.77	138.77	138.77	138.77	138.77	138.77	138.77	138.77	138.77	138.77
Area 1	0.00	0.00	25.00	54.00	58.32	62.99	62.99	62.99	62.99	62.99	62.99	62.99	62.99	62.99	62.99
Area 2	0.00	0.00	16.00	34.56	39.74	45.71	45.71	45.71	45.71	45.71	45.71	45.71	45.71	45.71	45.71
Area 3	0.00	0.00	10.00	21.60	25.49	30.08	30.08	30.08	30.08	30.08	30.08	30.08	30.08	30.08	30.08
Operating Expenses															
Personnel expenses	0.00	0.00	5.00	5.10	5.20	5.31	5.41	5.52	5.63	5.74	5.86	5.98	6.09	6.22	6.34
Maintenance	0.00	0.00	0.54	0.56	0.58	0.61	0.64	0.68	0.71	0.75	0.78	0.82	0.86	0.91	0.95
Marketing and Sales	0.00	0.00	2.55	5.51	6.18	6.94	6.94	6.94	6.94	6.94	6.94	6.94	6.94	6.94	6.94
Royalties	0.00	0.00	1.02	2.20	2.47	2.78	2.78	2.78	2.78	2.78	2.78	2.78	2.78	2.78	2.78
Insurances	0.00	0.00	3.00	3.03	3.06	3.09	3.12	3.15	3.18	3.22	3.25	3.28	3.31	3.35	3.38
Outsourced services	0.00	0.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Others	0.00	0.00	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.59	0.60	0.61	0.62	0.63
Total Operating Expenses	0.00	0.00	15.61	19.91	21.02	22.25	22.43	22.62	22.80	22.99	23.19	23.39	23.59	23.81	24.02
EBITDA	0.00	0.00	35.39	90.25	102.54	116.51	116.33	116.15	115.97	115.77	115.58	115.38	115.17	114.96	114.75
Depreciation & Amortisation	0.00	0.00	25.38	25.38	25.38	25.38	25.38	25.38	25.38	25.38	25.38	25.38	25.38	25.38	25.38
EBIT	0.00	0.00	10.01	64.87	77.15	91.13	90.95	90.77	90.58	90.39	90.19	89.99	89.79	89.58	89.36
Long term debt interests	0.00	0.00	10.28	9.20	8.07	6.89	5.64	4.33	2.96	1.51	0.00	0.00	0.00	0.00	0.00
Financial earnings	0.00	0.00	-0.07	0.64	1.52	2.58	3.63	4.67	5.69	6.69	8.60	10.52	12.42	14.33	16.57
Net interests	0.00	0.00	10.35	8.56	6.56	4.30	2.01	-0.34	-2.73	-5.18	-8.60	-10.51	-12.42	-14.33	-16.57
EARNINGS BEFORE TAX	0.00	0.00	-0.35	56.30	70.59	86.82	88.94	91.11	93.31	95.57	98.80	100.51	102.21	103.90	105.93
Income Tax	0.00	0.00	0.00	19.71	24.71	30.39	31.13	31.89	32.66	33.45	34.58	35.18	35.77	36.37	37.08
NET INCOME	0.00	0.00	0.00	36.60	45.89	56.44	57.81	59.22	60.65	62.12	64.22	65.33	66.44	67.54	68.86

Figure 7.5. Table of economic account.

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YEAR	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Cash	0.00	0.00	(2.11)	22.01	52.23	89.45	126.87	164.44	202.13	239.91	309.29	379.80	451.44	524.21	609.89
Accounts receivable	0.00	0.00	8.50	26.86	47.45	70.58	93.71	116.84	139.96	163.09	186.22	209.35	232.47	255.60	267.17
Other current assets	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL CURRENT ASSETS	0.00	0.00	6.39	48.87	99.68	160.03	220.58	281.28	342.10	403.00	495.50	589.14	683.91	779.81	877.05
Fixed Asset	104.00	330.00	330.00	330.00	330.00	330.00	330.00	330.00	330.00	330.00	330.00	330.00	330.00	330.00	330.00
Depreciation	0.00	0.00	25.38	50.77	76.15	101.54	126.92	152.31	177.69	203.08	228.46	253.85	279.23	304.62	330.00
TOTAL NET FIXED ASSETS	104.00	330.00	304.62	279.23	253.85	228.46	203.08	177.69	152.31	126.92	101.54	76.15	50.77	25.38	0.00
TOTAL ASSETS	104.00	330.00	311.01	328.10	353.52	388.49	423.65	458.97	494.40	529.93	597.04	665.30	734.68	805.19	877.05
Short term debt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accounts payable	0.00	0.00	1.95	4.44	7.07	9.85	12.65	15.48	18.33	21.20	24.10	27.03	29.98	32.95	35.95
TOTAL CURRENT LIABILITIES	0.00	0.00	1.95	4.44	7.07	9.85	12.65	15.48	18.33	21.20	24.10	27.03	29.98	32.95	35.95
Bank facility	24.00	200.00	179.06	157.06	133.97	109.73	84.27	57.54	29.47	0.00	0.00	0.00	0.00	0.00	0.00
LONG TERM DEBT	24.00	200.00	179.06	157.06	133.97	109.73	84.27	57.54	29.47	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL LIABILITIES	24.00	200.00	181.01	161.50	141.04	119.58	96.92	73.02	47.80	21.20	24.10	27.03	29.98	32.95	35.95
Equity	80.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00
Retained earnings (losses)	(0.00)	(0.00)	(0.00)	36.60	82.48	138.92	196.73	255.95	316.60	378.72	442.94	508.27	574.71	642.24	711.10
TOTAL EQUITY	80.00	130.00	130.00	166.60	212.48	268.92	326.73	385.95	446.60	508.72	572.94	638.27	704.71	772.24	841.10
TOTAL LIABILITIES AND EQUITY	104.00	330.00	311.01	328.10	353.52	388.49	423.65	458.97	494.40	529.93	597.04	665.30	734.68	805.19	877.05

Figure 7.6. Table of assets and liabilities.

YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Net Income	(0.00)	(0.00)	0.00	36.60	45.89	56.44	57.81	59.22	60.65	62.12	64.22	65.33	66.44	67.54	68.86
Depreciation	0.00	0.00	25.38	25.38	25.38	25.38	25.38	25.38	25.38	25.38	25.38	25.38	25.38	25.38	25.38
Changes in NWC	0.00	0.00	6.55	15.87	17.97	20.35	20.32	20.30	20.28	20.25	20.23	20.20	20.18	20.15	8.56
Cash flow from Operating Activities	(0.00)	(0.00)	18.84	46.11	53.31	61.47	62.87	64.30	65.76	67.25	69.37	70.51	71.64	72.77	85.68
Total Fixed Assets	104.00	226.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cash Flow from Investing Activities	104.00	226.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Long term debt proceeds	24.00	176.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Long term debt repayment	0.00	0.00	20.94	21.99	23.09	24.25	25.46	26.73	28.07	29.47	0.00	0.00	0.00	0.00	0.00
Equity + R&D Funding	80.00	50.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cash From Financing Activities	104.00	226.00	(20.94)	(21.99)	(23.09)	(24.25)	(25.46)	(26.73)	(28.07)	(29.47)	0.00	0.00	0.00	0.00	0.00
Cash beginning of year	0.00	0.00	0.00	(2.11)	22.01	52.23	89.45	126.87	164.44	202.13	239.91	309.29	379.80	451.44	524.21
Cash in the year	0.00	0.00	(2.11)	24.12	30.22	37.23	37.42	37.57	37.69	37.78	69.37	70.51	71.64	72.77	85.68
Cash end of year	0.00	0.00	(2.11)	22.01	52.23	89.45	126.87	164.44	202.13	239.91	309.29	379.80	451.44	524.21	609.89

Figure 7.7. Cash flow table.

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Timing		**Debt service assumptions**	
Project life span (years)	15	Starting Point of Repayment (year)	3.0
Investment Period (years)	2	LT Debt Interest rate p.a.	5%
Investment costs		**Ratios**	
Space segment	276	Project IRR	28.5%
Ground Segment	54	Project NPV @ 10%	413.9
Total Investment (capital goods)	330		
Depreciation (linear)		**Debt ratios**	
Space Segment	13	Lldscr	2.29
Ground segment	13	PCR	3.12
Intangible assets	0		
Working capital assumptions		**ADSCR**	
Accounts receivable (days)	120	Year 3	1
Accounts payable (days)	90	Year 4	2
		Year 5	2
CAPEX Coverage (investment period)		Year 6	3
Equity	61%	Year 7	3
Debt	39%	Year 8	3

Figure 7.8. Table of project assumptions and indicators.

Chapter 8

Management of Small, Low-Cost Space Programs: A New Paradigm

8.1. Small Space in Perspective

Small spacecraft were the first spacecraft. They pioneered all of the major applications of space (excepting human space flight) including spacecraft technology (Sputnik, 83 kg, 1957) space research (Explorer 1, 14 kg, 1958), remote sensing of the earth (Explorer 6, 64 kg, 1959), and communications (from low earth orbit, Telstar, 77 kg, 1962, from GEO Syncom 2, 35 kg, 1963).

With the US and Soviet emphasis on heavier launch vehicles and human exploration, and a demand for greater capability in remote sensing and communications, the focus of satellite technology shifted to larger platforms. Miniaturization of electronic and particularly digital devices requiring less electric power coupled with better batteries and solar panels and the availability of improved sensors and other payload elements by the 1980s enabled useful missions to be achieved in small spacecraft. On the demand side, space budget pressures and a desire on the part of smaller countries, amateur groups, and universities to gain experience in space combined to reignite interest in small spacecraft.

While it is natural to identify small spacecraft according to their mass, they are more accurately characterized by their complexity and the management structure used for their development. As complexity is reduced, both the engineering and the management of a spacecraft change. Small satellites are not miniature large satellites, any more than a single family home is a small skyscraper. Both are developed according to a set of technologies, of management structures, and of skill sets, some of which are overlapping, but they differ enough that their developers tend to be specialized in one or the other, as are the technologies they incorporate, their customer populations, and their applications. It is a sign of the maturation of a technology that a broader spectrum of capabilities and choices are made available to a wider spectrum of users. In transportation we have shoes, bicycles, motorcycles, a wide range of cars and SUVs, vans and small trucks, Semi Tractor Trailers, trains, a range of aircraft ranging from single seaters to 600 seat transport jets, and boats also ranging from single seat kayaks to ocean liners accommodating thousands of passenger and crew. We do not assume that the development of a shoe or kayak would be similar, in technology

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Space Technology Library 28, DOI 10.1007/978-1-4614-3755-0_8,

or management, to a cruise ship. Similarly space is now characterized by spacecraft ranging from a few grams to thousands of kilograms, and across this spectrum the methods of management and that which is managed vary radically.

8.2. Theory and Practice

While small spacecraft are known for their low cost, as little as a few hundred dollars, and rapid development periods, as short as a month, they also provide capabilities not possible with large spacecraft. Examples include swarms and constellations of large numbers of spacecraft, inspection, low earth orbit communications, rapid deployment, education, entertainment, extremely high ΔV for interception of other spacecraft or for rapid interplanetary rendezvous missions, and expendable missions such as impactors. Can one management methodology be applied to the entire range of small missions, from small academic programs with budgets of a few thousands of dollars to major military, civil, and commercial systems costing hundreds of millions of dollars?

Low complexity space programs have been developed since the 1950s. Their management structures and methods are well characterized. However, few missions are focused solely on low cost and complexity. Management is adapted from theory to the realities of each mission's requirements and development environment. However, as fluid mechanics exploits ideals such as inviscid flow and electrical engineers model components as if they were pure resistors or inductors, we start with the management of an ideal small space program and then via case studies look at how this model is modulated in real-world situations.

8.3. Scaling Management

Any activity involving more than one person requires a management structure. The more intuitive and ancient is the star structure shown in Fig. 8.1.

The Star management structure is characteristic of small satellite programs.

Every member communicates with each other, and the manager is in the middle of, not separated from, the other team members (Fig. 8.2).

This hierarchical structure is necessary to manage groups of size exceeding the ability of members to interact regularly with every other person.

Applications of the Star structure include management of a family, of a football team on the field, and of many well-known technological projects including the development of early musical instruments, the telephone, the airplane, and the intercontinental ballistic missile. In these latter cases the term "skunk works" is used to mean a small, highly interactive group of people, whose roles adapt constantly to the demands of the moment, operating without a formal set of rules and procedures. That this environment is highly desirable is evidenced by the popularity and extension of that term even to very large organizations which lack those qualities, though they may aspire to them.

It is desirable because it is highly efficient. Small groups can accomplish a tremendous amount with a minimum of management overhead. But why? And what are the limits of small groups?

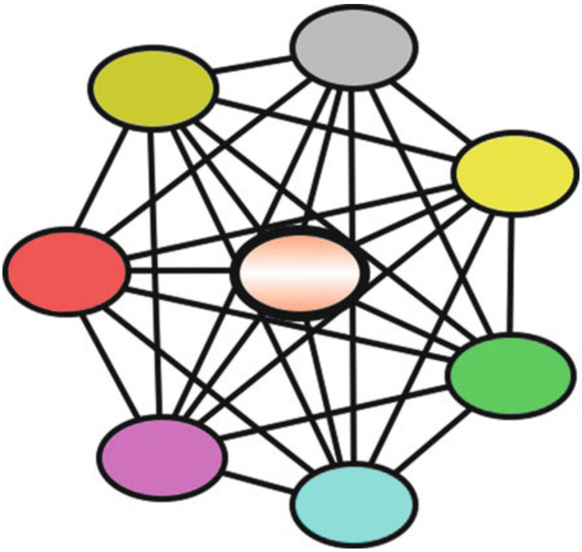

Figure 8.1. Star Structure.

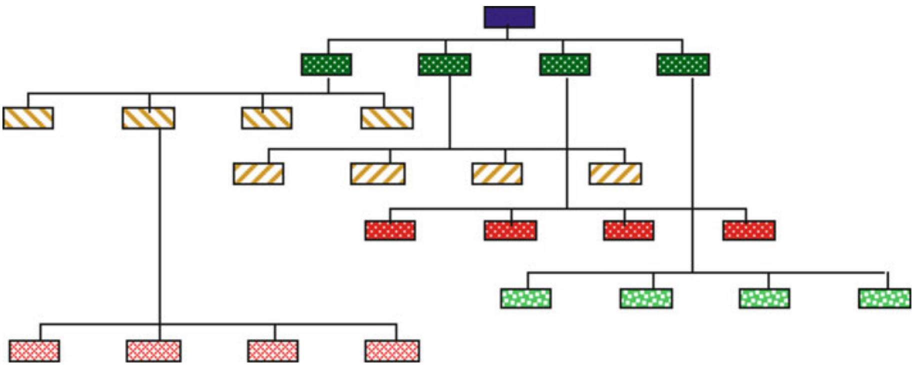

Figure 8.2. Hierarchical Structure.

Communications

All members of a small group communicate with all others. There is no sectoring of information. If for example a problem pops up in the attitude control system requiring more power, mass, or dollars, the entire team can focus on its resolution. They have the flexibility and authority to trade off a reduction in power budgeted for other systems, a reduction in the amount of data that can be processed and transmitted to the ground, or an increase in ground station antenna diameter, the cost of increased solar panel efficiency or size, or simply living with reduced attitude determination or control precision or authority. Further, the team can assess the risk vs. benefit of using a new technology which promises to provide the performance required within the established power (and mass, cost, volume, etc.) budget(s).

Roles

In the above example, the small interactive group can also redirect human resources. An engineer working on mechanical design or the communications system who is progressing more rapidly may temporarily help out in resolving problems in the ACS. The entire team can be brought together to brainstorm, and with all of the subsystems represented rapidly tradeoff the pros and cons of potential solutions.

Standards

In classic larger space systems we are accustomed to standards such as the mandatory use of space qualified components, to components with heritage in space, to specific assembly processes, test standards, materials, documentation, reporting, reviewing, and so on. The small team relies instead on the judgment of the members. The quarterback does not always pass the ball or hand it off or plunge into the defensive line. If an opportunity arises, that role may change suddenly to that of the offensive end to exploit the opportunity for a long run along the sidelines. A huddle may be skipped to save time. A small team can assess the risk of use of a nonqualified component compared with the advantages of reduced power, reduced parts count, reduced cost, mass, complexity, across all of the spacecraft systems, environments, and requirements, in a way that is impossible in enormous systems built by hundreds or thousands of people.

Jazz Ensemble

The fact that small systems operate more like a jazz ensemble than a symphony orchestra has made difficult, if not impossible, the initiative to write a "mil-spec" for the development of small, low-cost space systems. They by their nature do not follow a script, a musical score, but that a small team would make all of its own decisions without reference to rules borne of 60+ years of space experience seems like an invitation to repeat the failures of the past.

Staff

The organization of a small satellite team is tailored to its population. Even if there were a handbook of procedures to follow, parts selection criteria to be applied, success depends on people, on their experience, on their focus and commitment to quality, on their ability to communicate what they are doing and why, and especially to talk about their errors and failures of parts and architectural elements, to the rest of the group.

Commitment

In a sports team, a family and a small project, whether it is the church picnic or a small satellite, there is a level of personal commitment which energizes the group. These are not bureaucracies where the performers are hidden behind boxes on organizational charts. Small team members feel, and in fact are, closely identified with

the outcome. This stimulant has to be exploited carefully. The management problem switches from motivation of the staff to work to instead curbing their tendency to overwork, to take over too much of the problem, which can lead to overwhelming pressure, major delays, and ultimately burnout and the exit of a key player from the team.

Global Sharing

Despite the necessity to keep the team size small, to enable the rich network of cross communication necessary to achieve global sharing of information and optimization of resources, the manager needs to force additional staff into the team structure and not late in the program, after the team is overwhelmed, the design story is too complex and the staff too exhausted to educate a newcomer. All jobs are bigger than they seem at the outcome, thus overstaffing by 25% is absolutely required, as is stripping every possible requirement on the system not absolutely essential to the fundamental mission.

Requirements

Large programs are large because they are complex. They perform many functions for a variety of constituencies. GPS provides navigation, position and time information, as well as various associated communications and other services, to a global civil, military, and commercial user base. By contrast, a small satellite may do one very simple mission for one very small group of clients. The CRO system built by DSI in the 1990s did one such mission. In a mission lasting just a few days, it made its position known via optical sensing and on a single command expelled its payload of a single liquid chemical into space, for observation by a few scientists interested in the behavior of those materials when exposed to the space environment.

Micro-engineering

Micro spacecraft must have a very tight mission focus to remain small. The satisfaction of a larger community is accomplished through a multiplicity of small spacecraft programs, not through the imposition of multiple requirements on a single system and development team. The offense of a football team has the single goal of moving the ball over the opponent's goal line, and failing that to kick it over the goal post. It is well understood and readily shared among the team members, and progress toward that goal is obvious to all the team members at every moment during the activity. None of which is true, for instance, of a gate agent at an international airline, who may be optimizing the check-in of passengers to a single aircraft, but has no clear understanding even of the dynamics of that one flight, let alone how that flight's performance meshes with the fleet's operations of the day, with flight safety, with the airline's annual economic performance. The complex requirements of that large organization force management to focus individual workers on accomplishment of local, rather than global, objectives.

8.4. When Complexity Exceeds the Small Team Capability

Too often during the rebirth of microspace in the last 30 years, well-meaning sponsors have attempted to overreach the abilities of the small organization. A skunk works may turn out a new tablet computer with remarkable speed and cost efficiency, but that model cannot be extended to the production, distribution, marketing, sales, service, and customer support required when millions of that device are put in the hands of consumers around the world. Job One as a microspace program manager is to make sure the program you are managing is, and remains, possible for a small team of highly cross-linked individuals. And defending that structure is an ongoing challenge, as requirements for the mission tend to grow with time, as do the peripheral demands on the limited time and energy available from a small group of people.

Asked by the customer to accept a larger budget in exchange for more results, which may take the form of a more capable space system, or higher quality/space qualified components, or more frequent, more thorough reviews, or even a more highly redundant architecture, it is the manager's job to say no. It is counter intuitive that the addition of resources can destroy the project. But the choice is to keep the program within the small project envelop, or to change its nature to that of a large program, with formal division of responsibilities, formal lines of communication among specialist groups, formal requirements for components, procedures, assembly methods, test, every aspect of the product's evolution. But rarely, maybe never, does the client realize how large the budget impact is of this transition. It may be a factor of 10 or 100, but certainly not of 2 or 4. And it is the very rare case that a client is capable of a 100-fold increase in the funds available for a project. Thus those projects that fail to stay in that small project envelope face one of two outcomes: either the spacecraft is somehow completed and launched but fails on orbit (NASA's Lewis program) (see in particular http://spacese.spacegrant.org/Failure%20Reports/Lewis_MIB_2-98.pdf "Factors indirectly Contributing to Failure" which emphasizes the mismatch of team size and hence capability to the increase in requirements imposed upon it); or the program is cancelled (NASA's Clarke mission) (see *Science* 16 January 1998, Vol. 279 no. 5349 p. 318 "Goldin May Cancel NASA Earth Probe" which explains how as requirements grew and the small development team grew to accommodate them, costs accelerated well beyond forecast or budget realities for the mission).

Counter to intuition, the refusal of increased resources is the primary management tool for ensuring program success.

8.5. Staffing the Small Space Project

Too often the realization that success depends on individuals more than on formal standards has led to an "A-team" strategy, assembly of a team composed entirely of experienced veterans with a track record. This is impossible, since there are not so many of those people available and they often do not want to be immersed in the day-to-day details of yet another microsatellite's evolution. The A-team is also undesirable. As in the cockpit of a jet liner, a mixture of more senior staff with the judgment borne of experience combined with others less experienced but possibly more

adroit with modern design tools and more interested in day-to-day assembly and test activities is essential. It is this diversity of experience, ability, inclination, and point of view which is to a small program what all of the formal requirements, procedures, documentation, and standards are to a large mission.

This emphasis on staff is anathema to larger programs and is a major obstacle to the microspace program manager who will be under pressure to depersonalize the program so to avoid dependence on individual members of the team. This insurance comes at a high cost, diverting the team's time and energy into creation of documentation meant to explain to a person not now present what they did, will do, and why. An exercise that even in large programs proves at best marginally effective, the idea that a satellite could be created by a newcomer out of a cook book, much less one written by professional engineers who are not professional writers, and who themselves have yet to verify that their methods and designs will work being fundamentally flawed (see below).

The methods to protect from staffing changes in smaller programs are different. First, the chances of a team member exiting are less simply because the development program is shorter, typically a year or less. Compared with a major spacecraft program which may last 10, 15, or 20 years, in which staff turnover is inevitable, it is rare in a microspace program. Major programs are managed by division into thousands of individual tasks each one performed by an individual or group without need of contact with those performing other tasks. By contrast, in a small program ideally every team member has some contract with every task. The radio engineer is expected to help out in the power system even in the deployment mechanism used for a solar panel—maybe it could also deploy her antennas. There is a naturally existing buddy system. In an emergency that RF engineer could stand in for the power systems lead, at least until a new staff member can be added to the team, whom the RF engineer would then help to understand the work done so far.

It is the manager's job to make sure that this buddy system is in place for every element of the program. Engineers, especially software developers, have a tendency to simplify their work by not sharing it and thus saving the overhead of communication with others, and of adjusting to another's work habits. This behavior is not tolerable for many reasons. The loss of that person would in fact be a major setback to the program. There is no control on the quality of the work that person does, if no one else is involved in it. And if the job turns out to be more complex than anticipated, almost always the case with software development, there is no way other staff can help out, which is a fundamental mechanism of integrated team effectiveness.

A worker who cannot be trusted to function openly and actively with others must be eliminated from the team. Unlike management of large organizations and programs, which simply by virtue of their size must have among them a wide variety of workers and styles, the small team is hand-picked to have members with special qualities, among them close cooperation. There are no stars without whom victory is impossible, no A-teams of all elite workers with vast experience, no lone rangers who promise perfect on time work if and only if they are left alone for months, and there are no special cases.

There is one area where the manager should eliminate the buddy system, and that is in travel and meetings off site. Rarely is more than one person necessary for those meetings. The argument will be made that the expertise shared among multiple

people is necessary for the meeting. The failure of a meeting is less important than the failure of a spacecraft because the engineers were busy making meetings successful. One person goes, and the others are available for consultations by telephone if necessary, which usually they won't be.

8.6. How Small Teams Function to Reduce Cost

The small team reduces resource requirements—both time and money—in many ways. This is both a benefit and a trap. A program budgeted assuming it will be accomplished by a small team will be impossible to do via a more classically structured approach with work divided into individual independent packages and divided among groups which do not communicate and cooperate closely with one another. The program manager is thus committed to maintaining the small team structure, there is no other way the program can survive.

Flexible Requirements

The team must include the client because to reach the lowest cost overall solution, every element of the design must be in some sense negotiable. If the cost to further increase electrical power is large, say because to produce more power a deployed solar array will be necessary, all members of the team will look for power savings, maybe in the processor design, in the radio link, or in the operations of the payload provided by the client. There is no requirement not subject to renegotiation except that the team size is not allowed to grow and thus that the program and mission succeed.

Avoid Insurance

The classical space program budgets for mission assurance even in ways, like extensive documentation, which are of limited efficacy, because with the large amount of money and years of development at stake, the high visibility of major programs, and given that they have already committed to a readily scalable, albeit inefficient bureaucratic management structure because the small, cross-linked team cannot possibly achieve a program of their scope, the investment might be justified despite its cost and limitations. A small program must by contrast avoid documentation whenever possible, because the fundamental key to success is to limit the amount of work the small team must do. If the team is overwhelmed, quality will suffer, people will have to be added, and the management structure is destroyed. The program will fail or its cost and schedule will grow to the point of triggering the program's cancellation. Comparing this certainty with the tenacious hope that documentation rather than the buddy system of direct personal contact will make up for the loss of a key team member, it should be clear that wasting team member's time in documentation is to be avoided (documentation for small programs is discussed below).

Analysis

Most of the engineering analysis necessary for physically large spacecraft is unnecessary for small ones. Structures are often much stronger than necessary simply to use materials thicknesses which can be handled and attached to each other easily, obviating the need for all but an executive level strength analysis. A relatively heavy structure, usually of aluminum, of small dimension cannot support large thermal gradients; hence also the thermal analysis is reduced in most cases to a one-dimensional heat balance calculation. The team should be designing, building, integrating, and testing, not sitting in front of computers simulating, calculating, analyzing. The team is small, and there is not room for nonproductive activity to make us feel that failures won't happen. The system is simple—build it and test it. Ninety-nine percent of the time it will work fine and the other 1% would have probably been missed in analysis anyway. Worse yet, analysis will "find" problems that will not exist in the actual hardware, further wasting resources solving nonproblems.

CAD

Even more than finite element tools, engineers love CAD. It is wonderful to sit in front of a big hi-res screen and bring a perfect design to life while listening to music on the ipad. But not at work on a small satellite, whose structure is simple enough that at most a limited amount of CAD work is necessary. It should be designed mostly through hand sketches and conversations with the fabricators, who ideally should be the engineers themselves. Do not design it, just build it. If it gets built wrong, the investment is minimum, education maximum, and the second build will be perfect, turnaround time minimal.

Meetings

This is a team of people who work together constantly all day long. The entire project is a meeting. Larger programs meet for periodic reviews, the PDR and CDR, for example, which are an exercise in hiding from the reviewers any possible problem in the design, while the reviewers, faced with the impossible task of understanding and finding errors in designs barely understood by the people who have spent many months in their creation, justifies their role by creating action item lists the team must subsequently fulfill instead of building the spacecraft.

There are only two types of meetings necessary in a small team:

1. Internal regular (weekly) meetings to keep track of outstanding, unresolved problems. The team leader should maintain a list of these, and it will likely become very large, ranked according to their urgency, with dates by which they must be resolved and the person responsible for their resolution. These regular meetings should also serve as a reminder to the team to resolve these issues before they stall progress.
2. Technical Interface Meetings (TIMs): Instead of formal reviews, groups involved in each subsystem should meet informally with outside experts in those areas, to go over across a table the details of the design the assumptions inherent in it, concerns

and problems. The focus is on finding, not covering over, weak points and errors, without negative consequences instead with the goal of resolving them to the maximum extent possible during the meeting and without further analysis

Communications (Phone, Email, SMS, Etc.)

We live in an era of extreme communications overhead. The members of the team can expend a lot of time communicating with the outside world, particularly with the customer who will doubtless have each person's cell phone number for calls and SMS messages, and email address for more complex questions. The manager must set out from the beginning and maintain the discipline that absolutely no communications are permitted with the team except as triaged first by that manager. The manager's job is to protect the team from a stream which is in fact a deluge of questions, comments, opinions, and suggestions often offered with good intentions, by outsiders. Every team and manager must manage communications in the way that works for them, since email is a useful tool as much as it is a time sink. The most effective and least constraining method is to make clear from Day 1 that under no circumstances should email be exchanged with the customer without first channeling through the manager. Remind the team of this rule and emphasize why. Look for cheating and bring it up privately and publicly. Make it a campaign that you must be the sole point of contact and that you rely on the team to enforce that rule for and with you.

The largest communication overhead is usually created by the team's members and management. It is too easy to blame the customer, but there is a lot of chatter generated within the team. Discourage email discourse and encourage people to talk. Email is a waste of time spent typing, and worse, it leads to numerous misunderstandings, both interpersonal and technical, which then must be unknotted through management intervention and in-person conversations, all of which would be avoided by simply talking face to face or by telephone. It is incumbent upon management to preach and practice the avoidance of email whenever possible.

Documentation

To the maximum extent possible, the only documentation should be that which is produced naturally in the course of doing the engineering of the small spacecraft.

This "free" documentation includes:

- The contract including a mission's requirements document, and all associated modifications, invoices, and other contractual communications.
- An archive of all designs including all changes/modifications.
- An archive of all analyses including spreadsheets, Matlab models, etc.
- Budgets: parts lists, mass, power, thermal budgets.
- A photo archive of every minute element of the spacecraft at many stages along its development path. Also photos of every test setup, every time the spacecraft is packaged, etc.
- Videos narrated by an engineer or the manager of procedures, for instance the integration of the solar panels or payload to the bus.
- All emails.

- All test plans and records.
- All failures encountered in the development process should be documented and entered in the archives usually organized by the worker or the subsystem involved.

These may be simply a failure of an ordered part, a DC/DC converter, or of a circuit and the changes made to improve the circuit.

- Acceptance test records.
- Software: It is imperative that software be developed according to an agreed standard created and enforced by one of the engineers or the manager. The software must be thoroughly commented in detail so that to the maximum extent possible a person other than the author can understand the function of each line of code. Variable naming standards should be uniform across the program.
- All planning documents created by management. Most important among these are the outstanding issues list ranked per urgency, updated at least weekly and distributed to the team, and informal records of all conversations with the customer, particularly affecting the execution of the program—certainly requirements but also the details of who will do what action items by what date.
- Routinely produced management documents include cost and hours budgets, schedules, document trees, points of contact and the contract and contract modifications.
- All certifications, applications and other forms (e.g., for spectrum allocation).
- All financial documentation including purchases including vendor data sheets.

Simply archiving and organizing this documentation—all of which is produced automatically in the course of the program—provide a highly useful record of what was done during the program and what the product is that was produced. It is already more than will ever be read though it is almost always the case that buried among all the photos, videos and design and analysis records there will be information key to the success of the program. Capturing, organizing, and archiving all these multimedia data are some of the tasks that can and thus should be offloaded to a person other than the members of the development team.

Some formal documentation is necessary. The most important is the Interface Control Document (ICD) to ensure that responsibility for every element of the program is assigned to someone or some entity and associated with a delivery date. The creation, maintenance, and communication of the ICD are critical jobs of the program's management.

8.7. The Integrated Team

We live in a society of mass production of products at minimum cost (automobiles, computers, cell phones, Ikea furniture) and many of our notions on how work is done are affected by that pervasive environment, which is NOT characteristic of the microsatellite development arena which is most often characterized by a small team charged with building a one of a kind custom device of high quality and reliability. Thus it is important to review with the team how the work is done in an integrated product team environment.

The fundamental defining quality of this team structure is that we do it all and we live with the product from “cradle to grave” or in this case, concept to orbit. The team should not be confronted with specifications sheets, detailed budgets, and schedules, and then asked to magically satisfy all these requirements with limited time, dollars, and personnel resources. The program begins in a discussion of what the client wants out of their mission. Not specs, outcomes. The team is the systems engineering expert, and they are the appropriate group to translate the customer’s operational concept into a systems design including for example the orbit, the attitude control performance, the modes of communications, and on-orbit operations.

The same team that has identified these top level design elements then translates them into the increasingly detailed levels of design. There is no handing off from a customer engineering group to a contractor systems engineering group to a detailed design team to fabrication to test to integration, to launch ops and to operations. All of these functions are carried out by the same people who live with the program from before its inception through the accomplishment of the mission on orbit. Certainly there will be outsiders involved during various phases—specialists at test facilities, for example. But the responsibility for the execution is always with the team, and they must be present always with the hardware. Routine operations may be carried out by the client organization, but the team must remain a part of that team.

In all cases the rule is to avoid a situation in which the team is confronted with a problem resulting from something done to the system that the team was not aware of when it was done. This situation then requires the reconstruction of past events which is in practice impossible. Given that the team cannot monitor every command sent to the satellite over its on-orbit lifetime, the customer may be provided with operations software consisting of canned, pretested command modules which can be selected but not modified, which have been tested and proven reliable and not damaging. If the customer wants to do something beyond this vocabulary, the development team must be brought together to figure out how to accomplish this new capability.

The team members will perform their own shopping, and when desired parts are no longer available, they are individually responsible for finding substitutes and making required modifications to the design. They should be able to buy those parts on the phone or online with a credit card. There is no purchasing department, and the responsibility for receiving the parts and acceptance testing is with the engineer who ordered them.

There is no quality or reliability organization. These elements are built in, following the example of the team manager, to the way the team works. For instance, problems with functionality, a device which works sometimes but not always, as an example, must be discussed at least with the buddy and the manager, if not with the entire group. Failures of components must be documented. Quality cannot be imposed on a group by an external manager, nor subcontracted. It must be made the job of each team member. Similarly reliability is the result of a discussion among all members of the team of the failure modes, weak links of the operational chain, and tradeoffs on how to harden the design.

The cradle to grave strategy fits the small program because it eliminates the inefficiencies and errors inherent in handing hardware, software, and other design data off from one group to the next to the next. It eliminates the conversations between the buyer armed only with a parts list who has to refer back to the engineer

when a component is found to be no longer available. Engineers will complain that their time is being wasted in purchasing, and they are right. But globally time is saved through elimination of the buyer and the iterative buying process, and less obviously through working directly with suppliers, the engineer often finds new components, new ways of doing things, that a buyer would not have been able to leverage.

8.8. Parts Selection

A partial truth about small programs is that they use commercial off-the-shelf "Radio Shack" parts. The probability of the failure of one part within a system is calculated by the reliability of each part multiplied by the reliability of each other part. Each of these numbers is almost, but not quite, one, and as you multiply them together the resulting reliability falls rapidly (Fig. 8.3).

As the number of parts increases, for any given parts reliability, the overall reliability falls. Systems with fewer parts can use lower reliability parts and still achieve higher overall reliability, explaining why consumer electronics built with low quality parts, even when used in the stressing environments of the automobile, kitchen, and beach, nonetheless are more reliable than spacecraft.

Parts count varies directly with overall mass, and a spacecraft of 10 kg will have 1,000 times fewer parts than a spacecraft of 10,000 kg. Thus while a reliability of 0.9999 may be more than sufficient for the small spacecraft, no existing level of parts reliability is sufficiently high to assure there will be no failures in the bigger satellite. Thus it is logical that larger missions use the highest reliability parts available, and compliment their use with extensive redundancy in their design and in critical systems triple and quadruple redundancy. These measures have the opposite result in small systems. By complicating the design, raising complexity and workload, they stress the small team and waste resources that are then not available for engineering, building, and testing, and ultimately decrease mission reliability.

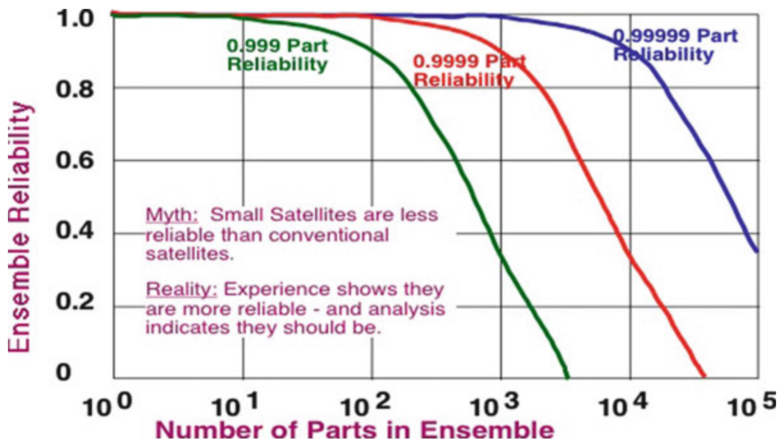

Figure 8.3. Reliability of Parts Ensembles.

Many terrestrial parts have very high reliability and particularly parts built for other stressful applications such as automotive use are quite suitable for spacecraft use. The small team is well positioned to take advantage of these parts because the engineer considering the use of a nonstandard part can check with all the other team members to rapidly discover any potential risks that part's use might carry with it. That person can then research the construction methods and materials and applications history of the part and carry on any additional tests necessary to qualify the part for use. On a large program this rapid communication across all program disciplines is impossible and no one engineer can understand the range of environmental requirements applicable to each component, implying that it is necessary to select parts from a predetermined list or list of standards that is uniform across the program, despite the costs, both in dollars and in complexity, that may entail.

The work of McDermott et al. ("Automotive Electronics in Space, Combining the advantages of high reliability components with high production volume" 0-7803-7231-X/01/$10.00/© 2002 IEEE) describes the use of terrestrial products for space application in detail. They highlight that there is a cost in time and testing to use these parts in space, so it is reasonable to ask if it is worth the trouble. Often it is because a single highly capable component found outside the space world, where heritage parts tend to be of previous generations, can replace an entire circuit board of older parts, reducing parts count which raises reliability per the above chart. Every part eliminated is a part which cannot fail. Highly integrated parts also eliminate complexity—or at least subsume it inside the part so that the team does not have to deal with it explicitly—and thus further contribute to reliability. By reducing mass and power consumption, these parts reduce the size, cost complexity, and risk associated with all the other spacecraft systems.

This largely technical consideration has an important impact on program management. The small program manager cannot accept requirements usually inserted in contracts to restrict the team to certain, often heritage or approved, parts, or parts that meet a certain mil-spec. This type of spec is representative of the rigidity necessary for product assurance in large programs and inappropriately applied to small ones. The avoidance of rigid standards allows for a different means of achieving mission success based on global, not local, reliability optimization.

8.9. Testing

Most of reliability is the result not of these considerations and conversations, but of testing. It is the manager's job to push the program through development quickly and inexpensively to reach integration and test with ample time and financial resources available for a long and thorough test program.

The manager will realize often that by slowing down the development process a more accurate design can result, with better analytical backup. But the counter argument, stated simply, is that an hour of testing is worth more than a week of speculating (analysis). Conventional large spacecraft programs are not cost constrained, they are requirements constrained. The contract and development standards dictate that the design must be reviewed and approved multiple times,

ensuring (one hopes) that a very thorough design and analysis process has been followed. And it specifies the analyses that shall be performed. The cost will increase to accomplish those requirements, and if it cannot, the program is not viable.

By contrast, a small space program is cost constrained, even if the customer offers to pay for overruns, because the team size is strictly limited as is the time it can be reliably kept together, as are the skills available within it. Outside help by analysts which appears a free resource is the opposite. The analyst must be made familiar with the design and with the details that make it up, and with what can be changed and not changed. If the analytical results point to problems, and they usually do, the team will have to refute those results through analysis and or test, or initiate changes that may ultimately have proved unnecessary. The program pace is slowed and though bureaucratically the team size is maintained, in fact the number of interfaces, of discussions, of meetings, is greatly increased.

In the cost-constrained mission, a dollar spent here is not available there. It is hard to argue against more analysis, better parts, and increased subsystem testing, except that each must be seen in the light of what won't get done because of the resources it expends. The only way to know a spacecraft works is to build it and test it. In a major program the cost of fixing an error is unacceptable, so analysis and subsystem testing must be thorough. In a small satellite, even very fundamental changes can be effected relatively quickly. Thus the risk balance switches toward building more quickly and instead testing more thoroughly.

The Thousand Hour Test

With the possible exception of missions lasting a few hours or days, the spacecraft must be shown to operate independently for 1,000 h without external intervention. Demonstrating this will take many more than 1,000 h, given that the system will doubtless fail this test several times. Better to fail that test in the lab than on-orbit, but as 1,000 h equates to over a month, the schedule must be built and enforced to maintain an interval of many months for integration and test. More time consuming than the 1,000 h test is the integration phase which proceeds it, probably the most frequently underestimated element of every space mission.

While the 1,000 h test is inevitably time consuming and expensive, there are compensating savings. Do not waste money simulating in elaborate test fixtures the on-orbit environment. Test the thermal model, not the thermal behavior on orbit. If the actual spacecraft behaves exactly per its model in any vaguely representative (i.e., vacuum) environment, it will predict the on-orbit behavior well enough. In many very small programs, the only thermal vacuum chamber is a bell jar, and in AMSAT for decades the only vibration testing was done with spacecraft bolted to bumpers of four wheel drive vehicles driven off road to shake up the hardware and see if it survived. While it is probably for the best that technique has been eclipsed, it is also true that in those years AMSAT spacecrafts were achieving better than 95% reliability, at least double that of the professional large spacecraft industry.

Parking Lot Orbit Test

Software is only one victim of the conventional development simulation syndrome where typically the spacecraft is tested in a sun simulating chamber—a vacuum chamber illuminated artificially with a light spectrum, direction, and intensity quite similar to that encountered on orbit. By contrast one of the most effective tests of a small spacecraft is to place it on a lab test cart with four wheels and, on a sunny day, roll it out into the parking lot where it must operate completely autonomously, charging its own batteries from the available sun, albeit filtered through earth's atmosphere, communicating via its radio receiver and transmitter and maintaining a sort of thermal equilibrium notwithstanding that it is not in space vacuum. Again we are testing the model. A calculation can be made of how much power the satellite should be producing for charging and operations in earth sun vs. space sun. If the actual hardware performs very close to that model, it is likely to also perform in space according to that model with the space insulation levels plugged into the model.

Small satellites do not employ major ground stations—typically the ground station is developed along with the satellite, based on off-the-shelf transmitters and receivers and a laptop computer controller. The spacecraft is thus tested and diagnosed not from a simulator, but from its actual ground station, zeroing the cost of a ground station simulator, another source of errors, particularly the ones that are often not discovered until the satellite is on orbit. The development team may complain that the serial (RF) interface to the spacecraft is not sufficient to do diagnostics, the response to which is the question "if it isn't adequate, how will the spacecraft be diagnosed if there are problems on orbit?": The ground station and spacecraft will be evolved to work around that problem and it will not turn up on orbit. In addition, by the time the spacecraft is launched, its team will have thousands of hours of experience operating it in its true flight environment. Reality is always the best simulation.

Another savings is in not environmentally testing every subsystem of the small spacecraft. The entire spacecraft is smaller and less complex than the subsystems typically tested individually before integration of a major spacecraft.

Avoid Simulation

Conventional systems built with expensive space qualified parts rely heavily on simulation particularly for software development. It is neither practical nor affordable to provide every software developer flight hardware as a development and test platform, so money is spent on simulation hardware and software which unfortunately is at best a distorted model of flight hardware and software realities. After paying for the simulation hardware and software, and for the time spent to assemble, debug, and understand them and their special development environment, more time is spent transitioning "final" software that ran on the simulator to the flight hardware, where it will have bugs. And since there is one or at most two flight hardware systems, the software development process regardless of the number of developers becomes singularly serial, and the entire program will spend money awaiting the completion of this critical phase, sometimes for many months.

Small spacecrafts built with commercial components have very low parts costs and hence can afford an to provide every developer an exact replica of the flight system,

eliminating the need for development and understanding of a simulation system, and the second phase of debugging of the transition to flight hardware.

8.10. Integration

Even very simple spacecraft programs spend much more than 1,000 h in the attempt to make a working system out of individual elements which all seemed to work fine before they were integrated. The length of this interval of intense work and frustration is inevitably underestimated by engineers, managers, and the client hoping to save time and money. In theory, expressed in the euphemism of the "success oriented program plan" the time to debug the newly integrated system is zero. It more typically is, like the roots of a tree, about equal in extent to the other more visible parts of the program. It is the rare program that has not needed much more time than budgeted to integrate the components and get the system working.

- Parts finding, ordering, and paying
- From customer concept (pre-specs) through on orbit launch
- Quality—a standard in common, neither imposed nor subcontracted
- Reliability: No reliability or quality engineer (no voltage or solder engineer)

8.11. Elements of the Small Program Plan

Managing a small team in many ways parallels building a small spacecraft in that the traditional complex tools developed for larger systems are unnecessary. While it is not useful to draw an organizational chart for six or ten people, there are management tools which should be employed to maximize the efficient use of the scarce resources available.

However, the most important principle characteristic of management of this class of programs is management from within, not from above. Managing an army of 100, 1,000, or more professionals in a traditional program requires a hierarchical system layering management layers to spread the reach of management eventually to each worker. By contrast, the small program manager is more similar to a nurse managing the care of a patient (the satellite) whose treatments will be performed by a small group of people—a couple of physician specialists, a physical therapist, a nutritionist, another nurse, some people who administer various tests representing the laboratory functions. The nurse's job is to work hands-on with the patient to ensure no element of the care is accidentally omitted, to ensure they do not all try to happen at the same time, to monitor their quality, to keep the process moving, to chart all that is done with the patient, and to interface with the patient and the patient's family (the clients) on progress. The nurse also shields the patient, sometimes even from the family, sometimes from caregivers who want to do more than may be called for, the nurse often provides documentation for insurance coverage and other bureaucratic necessities, and in general responds to whatever needs arise to achieve the desired outcome. The nurse is a team member who works shoulder to shoulder with all the caregivers and other concerned parties who is different only in that he or she has responsibility for the overall outcome and hence for the negotiation among all of the competing interests and activities effecting the patient.

To extend the metaphor, the nurse does not generally require an organizational chart; however, there is a care plan—what tests will be done, what treatments are to be applied in what doses and at what times, what is the appropriate environment for all of the required activities. When will the patient go to X-ray, to physical therapy, etc.

In our vocabulary this organization of tasks is the program plan. An example for a small spacecraft development will closely resemble this template (Fig. 8.4).

The plan assumes a program duration of 21 months from kickoff to launch. But the kickoff itself is assumed 2 months before there is a clear definition of requirements or of the specifications of the payload. Small missions do not begin with fixed requirements—they begin with a mission and the spacecraft engineering team works with the user to figure out how to meet the overall objectives in the simplest, most cost-effective way. Users cannot be expected to understand what functions might be more easily provided and which are more stressing. An example is the difference between attitude control and attitude knowledge. Tight control is more complex, heavier, and more costly than coarser control but highly accurate determination of the spacecraft attitude. These 2 months are the most important in the program and should not be omitted. They are where the experience of the team is challenged by the mission's requirements, where there is an opportunity to create an effective architecture that gives the client the desired result using a system that is simple, reliable, affordable, and buildable by a small team.

At the end of this phase of architectural concept development followed by creation spacecraft and payload specifications, the cost of the program will be to a large extent determined. Small satellite technology consists of finding ways to meet top level requirements using very small, simple systems, which is the goal of this phase, and then the ways in which those systems are realized. If a complex system with demanding requirements is the result of this period in which all stakeholders work together to develop a low complexity solution, the subsequent development program cannot be made small, rapid, and low cost.

We have seen how the attempt to create complex spacecraft using smaller mission methods led to the failures of the Lewis and Clarke NASA missions, either a technical failure on orbit, or a failure of the program to be executed near to the budget forecast and available. The same explanation might apply to AMSAT's OSCAR 40 spacecraft, which was at the time the most ambitious project ever undertaken by the organization, requiring 7 years and $4.5 million to realize. After 40 years of success building and launching smaller spacecraft, this attempt to realize a much more capable spacecraft on orbit, despite that it benefitted from a much larger budget, a larger more experienced development team, and a longer development schedule, resulted in a complete failure almost unique in AMSAT's history. While there must be a risk of failure in realizing new capabilities, and there are specific technical explanations for the failure of OSCAR 40, the low cost, rapid development, and high reliability demonstrated in micro spacecraft are ensured only in the development of systems of low complexity which can be developed on a brief schedule, less than 2 years, and by a team of less than 20 people, more conservatively less than 12 people. Not 12 superhumans working 24 h per day 7 days a week. Twelve normal people with all of their daily distractions and other commitments, with other managers asking for their time to solve other problems or work on proposals, working 8 or 9 h a day, 5 days a week. Setting realistic goals, limiting scope, makes the rest possible.

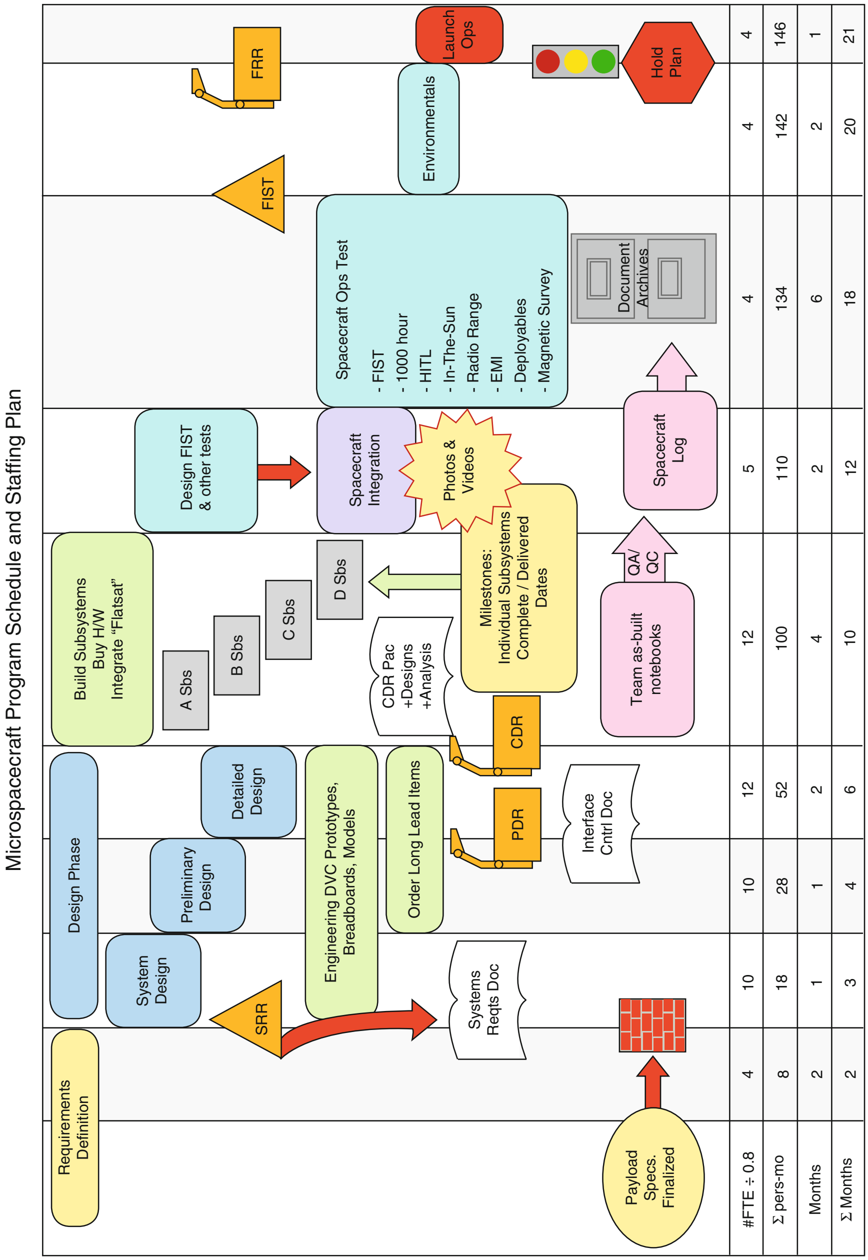

Figure 8.4. Program plan.

Because they are impossible to evade, the classic PDR and CDR are shown, not accidentally with an icon from decades past—an overhead projector. These management tools should be eliminated in favor of peer reviews and the buddy system, but as most contracts will require them, they should be managed. Use them to create documentation—to archive not just the design but the logic behind design choices. Some well-meaning person will one day say "why didn't you do X instead of what you did do?" regarding some element of the design. It is useful to say "we considered 19 ways to handle that problem and comparing them, chose this route based on our best knowledge at the time." Keep the reviews short, insist on doing them at your own location to avoid travel.

Possibly the most damage done by the culture of the PDR and CDR is the idea of waiting to buy (or even order) anything until the CDR is complete and signed off (which can happen months after the CDR if the reviewers succeed in creating a sufficient number of nearly impossible action items your team must complete instead of building the satellite). One way in which small missions differ from larger ones is that because the same team works on the satellite from concept to on-orbit, iteration is possible. In a classical mission, when the design phase ends, the project is turned over to the fabrication groups, and the design therefore must be frozen. Thus, when a part is found to be no longer in production, money is wasted to restart production. Failing that, or when the inevitable impossibilities are found in the design when it is put to the test of reality, the now-dispersed design team must be reassembled, at great cost and waste of time, and never completely possible, and asked to remember what they did and why, and now how to do it differently, while the fabrication team awaits the redesign, reordering of parts, etc.

Instead the small team begins ordering parts as soon as they are reasonably sure of their needs. Before the PDR ideally. If parts are not available, the design can be altered before too much effort is invested in its perfection and finalization. When parts come in subsystems are built—to discover problems early. This is particularly important for new and innovative elements of the project. Being compelled to do the CDR is a problem but mainly for your budget. Being constrained from buying and building from day 0 is much more damaging to the ability to manage budget and schedule.

If 100 assemblies are due on a date, and started in time to make that date, some percent will develop problems and be late. The entire program will then wait. The solution is to start each assembly process as soon as possible, and finish it as soon as possible, before it is needed. Only a few, if any, assemblies should be due even near to the date when integration will begin. The fewer, the less likely a delay. Avoid the delusion of partial integration—building a satellite without some of its components forces the team to simulate those components—the space they would take, for instance, to see if the rest goes together. It is at best a compromise. Better to have everything ready and dive into integration with the entire kit at the ready.

The team should be constantly archiving their designs, their communications, their analyses, photos, videos, and other notes about how things were done, blind alleys, failures. This should be a way of working every day, not an archiving task put off for a quiet day. There are no quiet days. Essentially your team should leave at the end of the day with the shop cleaned and orderly, meaning all notes are recorded, photos taken and sent to archives, failure reports done. Stop work 30 min early and enforce this habit. Eighty percent of the events of the day are forgotten by the next morning.

AeroAstro formalized a practice which in some form is a part of every mission, but often not recognized in smaller missions, that we called the FIST—Fully Integrated System Test. How do you know, after integrating and testing the satellite, that after disassembling it and shipping to the launch site in numerous boxes, and then reassembling it, that it is the same satellite, that it still works and would pass all the tests again if it were asked to? The answer is the FIST, designed by the team that builds the satellite, the FIST is a series of procedures that checks every aspect of the satellite's form and function. It is repeated every time the satellite configuration is changed—for a repair, for a shipment, for inserting and extricating at a test site. If it is instituted the very first time the satellite is made to work in fully integrated form, by the time of the launch the team will be highly sensitive to any irregularities. It is one thing to suffer a failure in orbit, but another to suffer a failure in orbit because the satellite launched was not the one that was designed, built, tested, and shipped to the launch site because some part of it was missing or broken. In general, spacecraft programs are highly attuned to look for exotic problems, but highly insensitive to the more likely failure causes, and the FIST is meant to protect from at least one of these.

The FIST is also 80% of the flight readiness review, which is a required review in virtually every program, big or small. There is no stronger evidence than a heritage test that has served you well for months indicating the spacecraft is exactly in its nominal state to ensure the customer that you are truly ready for launch.

One element more dangerous to a satellite than a failure to faithfully repeat the FIST is hurrying. Well-meaning managers seeing a little daylight in a schedule will ask for more tests, more meetings, more analysis, and more planning, to exploit that extra time. Why waste it? I advise not wasting it, but accelerating progress ahead of schedule. Rushing the spacecraft is no different than rushing out of the house in the morning to get to work in time—both seem like a good idea. But then half way to work when you realize you forgot the keys to your office, or your badge, or the flash drive with the final version of the presentation you have to make to the customer at 10 a.m., you are once again reminded of the folly of rushing. Which nonetheless we continue to experience, never quite learning that empty time to look around and rethinking everything before heading out has tremendous value. A well-managed program does not rush, it ticks ever forward, and it is ready ahead of time giving everyone time to think—did I forget anything.

That period of reflection exists in all space missions—the mandatory hold. Unfortunately the mandatory hold has now been filled with hold activities—it is even more mandatory, but it is not a hold. That is the stop light at the end of the mission. Stop and make sure you took off all the remove before flight covers, tightened the access port doors, connected the red wire to the plus side of the battery. The satellite might still fail but at least it will not be for a stupid reason. And if you eliminate the obvious, you eliminate most of the risk for hardware as thoroughly tested as yours will be assuming you left adequate schedule and money for integration and test, and did not waste it on overanalysis.

8.12. Case Studies

Engineering is an applied science and building small satellites is not about theory so much as about doing what needs to be done to get a certain capability done on orbit. No one program can span the entire population of situations, strategies, problems

resolved. In this section and in the next chapter, we look at a few selected programs to illustrate not only how specific elements of small program management are implemented, but also how these missions were kept simple, thus enabling a successful small satellite mission.

Early Programs

The renaissance of small spacecraft occurred through a series of programs in the 1980s and early 1990s which demonstrated that microsatellites could provide real utility beyond as projects for hobbyists. The Array of Low Energy X-ray Imaging Sensors (ALEXIS) spacecraft program was initiated in 1989 and launched in 1993. ALEXIS marked a change in the thinking about the role of microspace, transitioning it from the realm of amateur radio and hobbyist missions to an accepted tool for doing those space missions, for science, defense, remote sensing, or communications, which it can address. It is representative of the smallest and most cost-constrained missions which are performed under formal contract, comparable to many of the early SurreySats, the MightySat series, the smallest of the Operationally Responsive Space programs, the pathfinding DSI GLOMR store and forward comsats, followed by their Stacsat series and the Swedish Astrid series, among many others accomplished by companies, governments, and universities around the world.

All elements of the ALEXIS mission shared a commitment to achieve mission success by minimizing spacecraft complexity and imposition of formal program requirements on the small development team.

The medium-sized missions section of the next chapter analyzes missions that push the envelope of what may be considered and managed as small, to show how the ideals explained up to this point are modified to accomplish a somewhat larger, more complex and more formal mission, with more money at stake and a more critical mission to accomplish. This type of program and management environment is the predominant one in which the small space manager will find herself. Customers like the idea of small and low cost and fast, but they want all of the procedures and formality and assurances they are used to in large, slow complex missions. It is critical to be able to walk that tightrope. Missions in this category include in Sweden Odin and SMART, in Italy AGILE and MIOSAT, in the US STP-SAT, Tac-Sat 2 and JMAPS, in Germany RapidEye, in Israel OFEQ, and numerous others.

The future of microspace will in part depend on the successful operation of constellations and clusters, groups of small satellites to provide capabilities beyond those of a single satellite regardless of its size. Small satellites are the only economically viable means of fielding large numbers of satellites to provide a particular capability. We are already literally surrounded by examples of this approach in earth orbit—multiple geo imaging satellites provide global weather data, a constellation of GPS satellites makes possible global positioning and precise time keeping, the Orbcomm, Globalstar, and Iridium constellations provide global communications via hand-held devices. The multiple satellite section of the next chapter looks at the development of the second generation Orbcomm satellite constellation as a case study. A multiple satellite system differs fundamentally in its approach to reliability, and designing the program around this single principle highlights the special advantages and challenges associated with building a large number of identical satellites.

ALEXIS Satellite Program Management Case Study

ALEXIS began as a concept in the late 1980s not as a small satellite mission but as a plan to test innovative sensors developed by Los Alamos National Laboratory (LANL) as a payload attached to the Space Shuttle (STS), itself second to the international space station the largest spacecraft on earth. The LANL team was faced with numerous obstacles to that plan that typify the limitations of large space programs. The idea of carrying out a rapid test of their sensors in space as a milestone along a development program was incompatible with STS manifesting which is defined many years in advance, is highly competitive, and subject to change even very late in the program's maturation depending on higher priorities of support to human crews of the STS and the Space Station it serviced, to military missions, to exigencies of larger missions (e.g., if they require more of the STS's payload mass to launch), and to requirements of numerous international partners who depended on the STS.

As a shared platform, which is typical of almost all large spacecraft, the STS could not be compelled to point in the direction necessary for the test, thus during its 7–10 days in orbit, it was unknown how much actual test time would be available. Thus after years and millions of dollars of development time, it was possible the sensors would only be tested for a few hours, or not at all. Whereas to prove their efficacy for their intended mission, it was desired to have at least a few hundred hours of on-orbit operational experience in the desired spatial orientation.

As a human mission platform, the safety requirements of STS (and also of Space Station and other crewed vehicles and platforms) are extremely rigorous. This meant that the cost to develop the test apparatus and to prove its safety to NASA's review board would likely exceed the few million dollars available in the LANL R&D budget for the test program. Compromises to the design to accommodate the safety requirements would result in instruments flown not entirely representative of those planned for their ultimate application aboard robotic spacecraft without human crews.

The idea of instead launching a few sensors aboard a small satellite proved attractive because:

- Even 1 month on orbit lifetime would provide much more operational experience than even the most favorable STS flight opportunity.
- A dedicated spacecraft would be pointed full-time in the direction most favorable for testing the instruments.
- The instrument design and on-orbit operating environment would be identical to that planned for their eventual deployment.
- From an organizational point of view, LANL saw an opportunity to decouple their activities from the rigidity of the NASA manifest constraints, especially the mission prioritization and scheduling, not only for this mission but for the future, if the microsatellite approach would prove successful.
- The test was not an operational mission with national security implications. As an R&D activity, it was not constrained by the procedures and processes which must be implemented in operational programs.

The laboratory carried out a series of internal and funded studies to determine potential architectures, project costs, and schedules and assess the likely capabilities

of a low-cost micro spacecraft host for the ALEXIS payload, resulting in a formal request for proposals in 1988 and a contract award in 1989.

The studies provided the opportunity for the first phase of the microspace program—trading off requirements against those elements which are difficult or hard to accomplish in a microsatellite platform. Los Alamos had envisioned a full three-axis stabilized platform with a suite of four momentum wheels. In the study it was determined that in fact the spacecraft could slowly spin, rotate about one of its axes, and eliminate the need for momentum wheels to achieve attitude stiffness. Other innovations which enabled the mission to be accomplished via the small project paradigm included a communications system which did not require continuous contact but rather accommodated interruptions in the signal as the spacecraft rotated, accomplished in software, elimination of propulsion for attitude control in favor of a magnetic system requiring no thrusters, tanks, valves or propellant, use of a terrestrial microprocessor, the Intel 8086, which at the time offered much lower cost and power consumption with much higher computing power than space qualified alternatives, a dedicated micro ground station at Los Alamos instead of using Air Force facilities which while highly capable also impose numerous requirements on the spacecraft, and to accommodate this single, simple ground station, a very large on-board digital memory, also based on terrestrial, commercially available RAM, to store data accumulated when the satellite was not in range of its ground station.

The result of a highly competitive procurement process was the selection of AeroAstro as the spacecraft contractor, contracted at a price of $1.8 million for a 10-month development effort followed by a similar length effort to be accomplished at Los Alamos where the payload would be integrated to the satellite bus. The parts budget, composed of many terrestrial or custom built elements to constrain cost, accounted for about $700,000, thus leaving a total labor budget of about $900,000 after subtracting other costs including travel.

Over a 2-year period this implied an average staffing including management of eight to ten people at contemporary labor rates. As a very small business, at the time operating out of a suburban residence, AeroAstro's overhead rates were very low, labor overhead below 50% and General and Administrative overhead below 10%. Had the job been awarded to a conventional contractor, that labor budget would have instead supported three to four people and the project would not have been possible. Small missions do not require the large, sophisticated development and test facilities (including high bays, clean rooms, large thermal vacuum test chambers) characteristic of major programs, allowing them to be built in a home (as was done for tens of AMSAT missions), university, or in the test bench environment made available at LANL. Thus this overhead rate is not anomalous but rather a result of the cost structure of an organization designed expressly for developing simpler and smaller space systems (Fig. 8.5).

ALEXIS integration in shirtsleeves environment at LANL flight solar panels visible in bubble wrap on tabletop lower left.

HETE

The desktop development environment was neither special to ALEXIS nor Los Alamos. Virtually every small satellite is designed to be built and tested in a normal laboratory environment because the additional time and cost of operating in special

Figure 8.5. ALEXIS Shirtsleeve Development Environment (courtesy Rick Fleeter).

environments and the special care required of a fragile product which could be damaged in contact with the everyday environment are neither compatible with a small budget and team, nor with reliability except for those programs with large enough budgets to ensure that all of those environmental requirements can be maintained over the life of the spacecraft. The MIT/NASA HETE (High Energy Transient Experiment) satellite shown below is another of many such examples. These and other missions developed on kitchen tables, in university offices, and in industrial shops have proven highly reliable on orbit. ALEXIS operated for 12 years and was intentionally shut down having more than accomplished its mission. HETE remains operational on orbit many years beyond its projected lifetime (Fig. 8.6).

Program Planning

The program plan did include two formal reviews, the PDR and CDR, which were carried out at Los Alamos staffed by about six AeroAstro engineers and about double that number of Los Alamos personnel. The reviews were each compressed into 1 day with a half day follow-up for discussion of issues raised and were an opportunity for problem solving, not evaluation (the two do not mix). The program management team at Los Alamos undertook the difficult job of shielding the program from the Laboratory's infrastructure normally activated for monitor and control of their space and high reliability programs.

The justification was that the ALEXIS program was not mission critical and was of limited scope and budget. Nonetheless, this was politically and bureaucratically

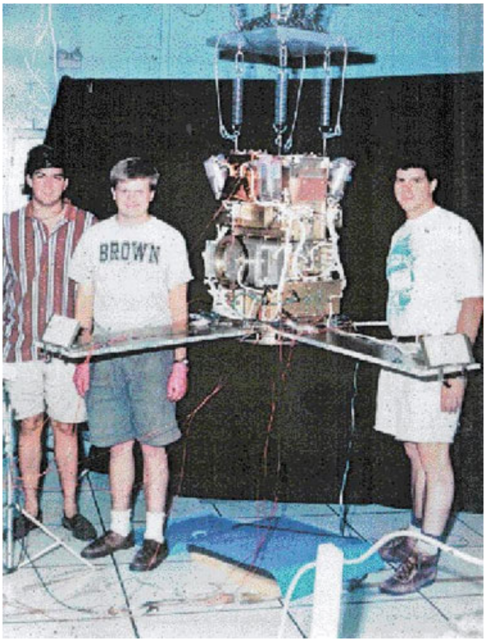

Figure 8.6. HETE (courtesy Rick Fleeter).

difficult and unpopular. It was illustrative of a problem the small program manager very often faces—protecting the program from the processes and procedures imposed on larger programs—for reviews, for documentation, for controls on procurement, on quality, on testing, on every aspect of the design, build and test flow, which are not compatible with the capabilities of a team composed of a few individuals charged with design, development integration, and test of an entire spacecraft in less than a year. But these procedures are bypassed not just for economic or managerial reasons. They are imposed on small programs based on the (incorrect) assumption that every space program has the same management requirements. But a small satellite is much less like a large satellite than it is like a small custom built terrestrial device like an automated antenna test machine or a specialized factory floor robot, devices that are not developed with management procedures similar to those of a major space program. These methods are inappropriate to a small mission in part because reliability depends less on controls and formal communications via documentation and management structure, and more on the simplicity of the design and hardware and the close and detailed communications which can only be realized among members of a small highly cross-linked team.

ALEXIS Time Management

In minimizing cost we have talked about controlling the program scope and complexity, thus allowing use of a small team, managing appropriately for the small team, basing the program at an organization designed for simpler, smaller space programs, and resisting peripheral activities including extensive reviews and documentation and frequent communications between organizations directly with

members of the development team, which while proffered as aids to a successful program outcome instead expend resources and extend program duration, stealing resources that otherwise could be applied to the critical functions of engineering, build, test, integration, integrated systems test, and so on.

The program manager is acutely aware that time is money. While in theory staff could be transferred to other projects when not immediately required on ALEXIS, the practice is impractical and undesirable. Once transferred the memory of what was engineering and built, and why, fades rapidly and the getting back up to speed is costly and risky. Sometimes the staff member is not available immediately to rejoin the program, creating further delays for the others, or requiring her or his replacement with the subsequent costs of time for training and integration into the team, and of fidelity of information. New staff inevitably bring with them new ways of doing things and often spend time redoing work already done in another way. When staff are on travel, for meetings and especially for the launch campaign, their expenses cannot be reduced in case of delays.

The acute financial pressures on ALEXIS were in part addressed through minimization of complexity of the spacecraft and thus of the size of the staff, number of meetings, and reliance on many "hi-rel" space practices, but also through compression of schedule. The manager must find, however, a balance. Extreme time pressure can go beyond the minimum cost point. To save even more time, express shipping which costs more, pressure on the team which causes errors or burnout, are counterproductive. Management is about judgment and the manager at the center of the program is positioned to design the schedule to minimize global cost. Management is a creative job requiring imagination, finding ways to do things in innovative ways to reduce work and hence cost and particularly in small programs, this talent and the interpersonal skills for implementing innovative methods adapted to specific program factors is critical.

Particularly illustrative of this point is the ALEXIS launch campaign. Recognizing that sending an integrated Los Alamos/AeroAstro team out on an extended campaign away from our bases would be a budget-buster, a streamlined launch campaign staffed by three LANL and three AeroAstro personnel, compressed into 15 days was designed and executed. The satellite was in orbit on the 16th day after being loaded into a truck at Los Alamos for transport to the launch site, the runway at Edwards Air Force Base, California where a B-52 would carry it, integrated onto the Pegasus rocket, on the first leg of the trajectory to space.

The figure below shows the day-to-day timeline of the launch campaign. Innovative elements include the use of our own staff to transport the satellite, and themselves, to the launch site in a single truck following by a staff car. The spacecraft, its ground support equipment and spares, and its team, could not help but arrive together. Pegasus itself was designed for rapid launch. The major challenge was adapting the staffs involved, of LANL, AeroAstro and the Air Force, to the planned pace. The FIST at this point had been performed multiple times and required only a few hours to verify, to the team and to the clients, that the spacecraft was in fact in the same condition it had been before ship. Management had communicated the compressed schedule to the Air Force so that all staff were available at the site avoiding waiting for the organization of the required readiness reviews (Fig. 8.7).

ALEXIS Satellite Launch Timeline

1993, March 8	Flight readiness review complete at LANL
April 10	Truck with ALEXIS and Ground Support Equipment leaves Los Alamos for launch at Edwards AFB
11	Truck arrives EAFB
12	Unpack satellite and cround support equipment
13	Mission Readiness Review (USAF)
14	FIST (Fully Integrated System Test) and launch rehearsal
15	Battery and Connector Closeout
16	
17	Final FIST
18	Rest / hold day
19	Pegasus Launch Vehicle flight review
20	Launch vehicle integration planning
21	Pre-mate preparation
22	Mate to Pegasus, Install fairing
23	Mate to Pylon adapter that attaches to launch aircraft
24	Rollate and mate to B-52 launch aircraft
25	Air drop and launch to orbit from B-52 at 6:56 AM local time

Figure 8.7. ALEXIS Launch Timeline (courtesy Rick Fleeter).

A team of six from the payload and bus organizations took ALEXIS from the clean room at Los Alamos to launch in 16 days.

The government procurement process is bureaucratic and takes time, and a system design benefits from time to create and iterate to find the most efficient means to accomplish a mission. With time and motivation, the complexity and eventually the size and cost of the mission can be dramatically reduced. The ALEXIS program overall timeline shown below illustrates that despite its supposedly abbreviated schedule in fact the period from mission conception through launch was 6 years (Fig. 8.8).

ALEXIS achieved low cost because time was expended early in the program when the rate of spending is minimal to achieve the most efficient system and program design possible.

Most of these 6 years were spent in studies aimed at minimizing mission requirements, minimizing system complexity, and designing a development program, tightly integrated between key performers, the management and payload developers at Los Alamos, the bus supplier/contractor, the launch organization and the Los Alamos and US Air Force oversight, that could be accomplished with minimum staff and time. The key concept is that the rate of spending at the concept stage is minimal, a few thousand dollars per month, whereas a month of operation for a 12-person team plus equipment on lease, facilities, management at the payload/client organization, and other associated direct costs such as travel and infrastructure can cost 100 times as

ALEXIS Spacecraft Program Timeline

1987	Mar – May Mission Conceived at Los Alamos and studied
	June – Nov Mission Feasibility studies at Los Alamos
1988	Mar – May External Studies funded by Competitive Procurement
	Nov Request for Proposals for Satellite Procurement issued
1989	Feb Contractor selected
1990	Jan Spacecraft Bus delivered to Los Alamos for test and integration
	Nov Bus tests completed
1991	Mar – May Payload Integration
1992	Mar – May System Testing complete and ready for launch
1993	Apr Launch
...	
2005	ALEXIS operation ends

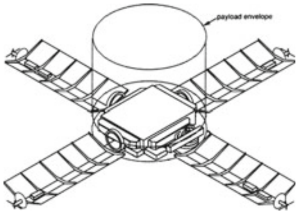

Figure 8.8. ALEXIS Program Timeline (courtesy Rick Fleeter).

much. Time spent early in the program to find every possible efficiency throughout the program lifetime, and continuing to address these innovations throughout the program lifetime is always a good investment.

8.13. The Requirements Trap

The practice of large space programs of issuing complicated lengthy and detailed tender calls with every aspect of the program already spelled out in detail is anathema to low cost. The greatest value of the integrated team is the interactive search for savings, not just in money, but in complexity, in risk, and in schedule which is made impossible by the rigidity built into what has become conventional space program management. The lack of flexibility and reliability on fixed specifications and procedures is not unique to space and is found throughout the sphere of major systems development—in air, space, sea, and on the ground, for instance in the development of a skyscraper or large bridge or power plant. It is not, however, found in small projects involving less than 10–20 staff. To impose the methods of either one upon the other is a formula for disaster. Keep the program small, the engineering simple, the timeline short, and use the methods best suited to that environment, those described in this chapter.

If for reasons of mission difficulty or the management environment in which the mission must be performed these minimizations are not possible, the appropriate management method and organization will change. This does not necessarily mean return to the full blown large program model. Many if not most “small” programs are too big to be accomplished according to the ideal model described in this section, and over the past 20 years a new hybrid category of intermediate missions has become possibly the fastest growing segment of space missions, comprising programs with budgets from $10 million to a few hundred million dollars, and usually involving spacecraft with mass between 100 kg and 500 kg. The next section addresses the management of these medium-sized missions again using a few successful programs as case studies.

Even in a medium class mission, the concepts of absolute minimum mission execution serve the manager as an ideal to strive for, tempered by the realities of the more complex and larger program.

Chapter 9

Examples of Management Applied to Different Space Programs

Here below three different types of space programs are described. The focus on the program management provides points of views for understanding strategies and methods to achieve a successful space mission.

9.1. Large Civil Governmental Satellite Program: The NASA Advanced Communication Satellite Program Advanced Communications Technology Satellite

The section is an extract of the book "The Advanced Communications Technology Satellite" written by Richard Gedney, Ronald Schertler and Frank Gargione, published in 2000 by SciTech Publishing Inc. The reproduction of this text has been authorized by the authors.

Program Conception: A Mix of Politics and Technology

In 1978, as a result of the Presidential Directive, NASA began the process of rebuilding its R&D activities in the communication satellite arena. The future technology program was planned in cooperation with the National Research Council's Space Applications Board Subcommittee on Satellite Communications, whose membership consisted of leading common carriers, spacecraft manufacturers, and representatives of communication users.

In this first phase of the NASA program, market and system studies were conducted to determine future service demand and whether or not C- and Ku-band satellites could satisfy it. Two contracts were awarded to common carriers: Western Union Telegraph Company and U.S. Telephone and Telegraph Company, which was a subsidiary of International Telephone and Telegraph (ITT). The emphasis of these studies was to forecast the telecommunications traffic that could be carried by satellite competitively. During this same time frame, two other system studies were conducted—one each by Hughes Aircraft and Ford Aerospace, with supporting studies by TRW Corporation, General Electric GE, and the Mitre Corporation.

Their purpose was to identify the technology needed to implement cost-effective and spectrum-conservative communication systems. The results were combined to

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define potential commercial system configurations that could address the market for trunking and customer premises services that was expected in the early 1990s. System requirements derived from these postulated commercial configurations formed the basis for the technology development program that followed.

The market studies predicted that rapid growth in domestic voice, data, and video traffic would lead to a fivefold increase in U.S. communication demands by the early 1990s. A combination of these market projections and communication satellite license filings with the FCC portended a saturation of North American orbital arc capacity using the C- and Ku-band frequencies.

To relieve the pressure of this expanding market, the 30/20 GHz frequency band was needed.

As a result, the new NASA communication program for commercial application was named the 30/20 GHz Program and was structured to:

- Develop selective high-risk, 30/20 GHz technologies that focused on relief of orbit and frequency congestion and developing new and affordable services
- Promote effective utilization of the spectrum and growth in communications capacity
- Ensure continued U.S. preeminence in satellite communications

The technologies required to meet these objectives were judged to be of such high technical risk that they were beyond the capability of any one company to finance (Figure 9.1).

In 1979, NASA designated the Lewis Research Center (LeRC) in Cleveland, Ohio, to be its lead center in planning and executing the commercial communication satellite technology R&D Program. In 1999, the LeRC's name was changed to the Glenn Research Center (GRC), in honor of John Glenn, astronaut and U.S. Senator from Ohio. Early communication satellite systems employed simple, bent-pipe transponders with a single antenna beam to cover a large region (such as the continental United States).

The new NASA program needed to develop technology that would allow the frequency spectrum to be used more efficiently. One technique to accomplish this was to cover the region with many small spot beams so that the same frequency could be reused simultaneously in nonadjacent beams. Such frequency reuse increased the capacity of satellites by a factor of five to ten times that of a single beam satellite, with only a modest increase in spacecraft size, power, and weight. The technology to accomplish this high degree of frequency reuse employed antennas with high-gain spot beams and electronic systems with onboard switching and processing to interconnect the spot beams. In addition, the high-gain antenna allowed for smaller aperture user terminals at higher data rates. This was the technology developed by NASA (Figure 9.2).

Technology Feasibility and Flight System Definition

In 1980, the program moved forward in two phases. The first phase was to:

1. Continue the market studies to increase confidence in the forecast for orbit saturation.
2. To do proof-of-concept (POC) development of the identified technologies.

The POC program was a laboratory (breadboard) type of development to prove that the technologies were feasible. Approximately $50 M was expended on the first phase.

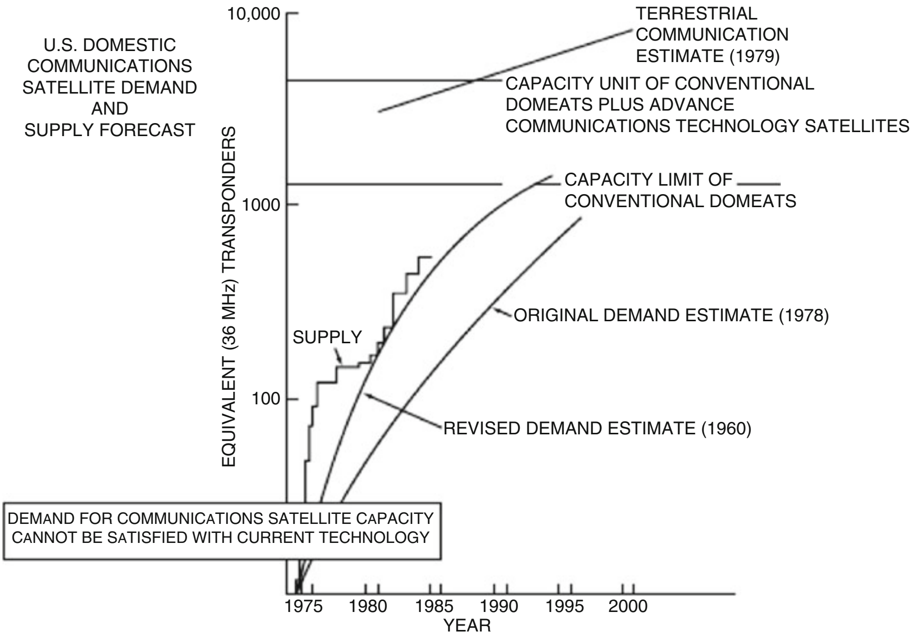

Figure 9.1. Satellite addressable market demand. ("The Advanced Communications Technology Satellite" book source).

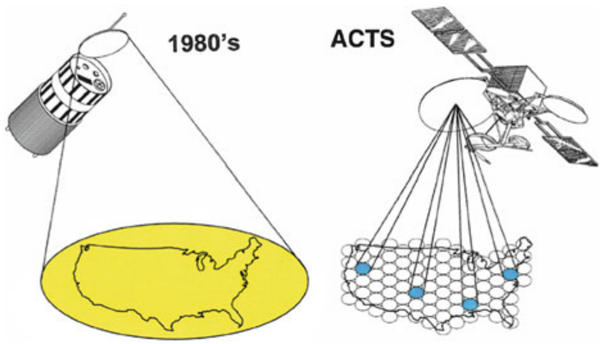

Figure 9.2. Wingle beam versus multibeam satellites. ("The Advanced Communications Technology Satellite" book source).

If the first phase proved successful, the second phase would consist of developing an experimental flight system to demonstrate that the technologies could provide reliable communication services. The first phase was fully supported by the entire service provider and satellite manufacturing community. The second phase of the program was the one that became controversial. The service providers had great concern about how reliably the technology would work in space, and therefore, argued for a flight program. Some satellite manufacturers, however, had reservations about proceeding with a flight program because they felt it would give the winning contractors of the

NASA procurement an unfair competitive advantage. This controversy continued throughout most of the life of the Advanced Communications Technology Satellite (ACTS) program.

Program Coordination with Industry

Two industry committees were formed to guide the program. The NASA Ad Hoc Advisory Committee was created to provide general policy direction. The committee included notable representatives of both the system supplier and service supplier industry. Their contribution provided timely and sage review of the program, as well as providing NASA with insight into the industry philosophy relative to the roles and responsibilities of both government and the private sector.

The second industry committee was a Carrier Working Group (CWG), consisting of representatives from all the major satellite service providers. The CWG was charged with helping NASA formulate the technology and flight system requirements, develop experiments, and provide overall guidance. These requirements and experiments were deemed necessary by the CWG to demonstrate the readiness of not only the technology, but of its service applications as well.

Coordination was also established between the Department of Defense (DOD) and NASA, especially in the development of various critical advanced technology components.

POC Development

The purpose of the POC technology development was to demonstrate the technical feasibility of the key component building blocks. The approach NASA used was to issue multiple contracts to various aerospace and related companies for the development of each high-risk technology: multiple spot beam antenna, base band processor, TWTA, wide-bandswitch matrices, low-noise receiver, GaAs FET transmitter, GaAs transmitter, and ground antenna.

Duplicate awards for most of the critical technology components were employed to increase the probability of successful development, and to produce multiple sources for communication hardware. In addition, multiple awards helped to ensure that a variety of perspectives and technical approaches were brought into each development.

These contracts called for the development of the technology, the construction of POC versions of the components, and their testing in the laboratory to verify performance. The POC hardware substantially reduced the risk associated with the planned development of the flight system. Another product of these technology contracts was the prediction of feasible component, subsystem, and system performance levels. NASA used these performance predictions to provide guidance for follow-on technology development. Service providers and manufacturers could also use these predictions in planning activities for the commercial system designs of the early 1990s.

The DOD participated in the NASA POC program. Several of the critical technology POC elements that were of interest to the DOD were co-funded by DOD and NASA. To enable the effective transfer of information that was generated in the program, all contractors were required to prepare task completion reports. These reports were presented at periodic industry briefings (only for interested U.S. parties) hosted by NASA.

Flight System Definition Studies

The need for a flight test program reflected the fact that much of the required technology had never been demonstrated in space. The flight test was to ensure that the technology base was mature and validated, providing the level of confidence recommended by industry as being necessary for commercial exploitation.

The initial planning called for two experimental satellites to be built and flown; one to demonstrate telephone trunking for high volume users in metropolitan areas, and the other to demonstrate customer premises services using small and inexpensive earth terminals located at customer locations. In 1980, the two-flight concept was reduced to a single experimental spacecraft, primarily emphasizing customer premises services.

This proved to be a wise decision since the introduction of fiber optics a few years later significantly reduced the cost for terrestrial trunking services, making satellites noncompetitive. In February 1982, Dr. Burt Edelson became NASA's associate administrator of the Office of Space Science and Application, and played a very important role in keeping the program alive.

When the program was seriously threatened in 1982, Dr. Edelson restructured the 30/20 GHz program by broadening its applicability to the entire frequency spectrum for satellite communications.

As a result, the experimental satellite system was renamed the ACTS, and it focused primarily on the technology of multibeam antennas (MBAs) and associated onboard switching and processing. Spacecraft capacity was reduced to a minimum for technical verification and experimentation only. Dr. Edelson provided key leadership for the ACTS program during his tenure at NASA, and has been a vocal proponent of the program and its benefits ever since.

Two other NASA managers who provided important leadership to the NASA Communications Program were Joe Sivo and Bob Lovell. Joe Sivo was the chief of the Communications and Applications division at NASA's LeRC in Cleveland, Ohio. Joe was the "Father of ACTS" and led the LeRC team in the late 1970s and the early 1980s as NASA restructured its communication program. Bob Lovell became chief of the Communications division at NASA Headquarters and worked with both Dr. Edelson and Joe Sivo to structure the ACTS program and guide it through technical and political hurdles in the early 1980s. Without Sivo, Lovell, and Edelson, the ACTS flight program would have never gotten off the ground.

Concurrent with the POC technology development, NASA was working with industry to define flight system concepts that would demonstrate ACTS technology readiness and its service capabilities. During the period of 1981–1983, the major spacecraft manufacturers, Ford Aerospace (now Space Systems Loral), Hughes Aircraft (now Boeing Satellite Systems), TRW (now Northrop Grumman Corp.), and GE and RCA Corporation (both now part of Lockheed Martin) were funded by NASA to conduct system studies for defining an R&D spacecraft (ACTS) that could be flown by NASA. NASA then used the results from these system studies to develop the Request for Proposal (RFP) for the ACTS spacecraft and ground system.

This RFP was issued by NASA in early 1983, with a proposal due date of June 1, 1983. Since the RFP required the development of very high-risk technology that had never been flown before, a cost-plus-fixed-fee type of contract was specified. The five

separate flight system studies were conducted to get a wide range of views on what the ACTS spacecraft configuration should be and to promote competition for the procurement of the spacecraft.

As it turns out, this process did not accomplish the latter objective and was complicated by the fact that there was not a clear consensus for the need for a flight program to prove the feasibility of the new technology.

The Reagan administration espoused a minimal government involvement ideology. At the time, the Republican administration took the position that it was not the proper role of government to conduct a flight program for the purpose of proving technology for commercial purposes, especially for a profitable industry.

There were many arguments presented by the Republican administration as to why the government should not sponsor the flight verification.

These included arguments that the government was not capable of predicting technology for commercial application, and that the spot beam, frequency-reuse technology was not necessary because there was plenty of C and Ku-band spectrum for future use. However, as we know today, the use of spot beams allows a great increase in the amount of frequency reuse so that a single satellite can have a very large capacity.

Without this spot beam increase in capacity, many of the mobile and broadband satellite systems under development in the late 1990s, such as Iridium, Globalstar, Spaceway, Astrolink, and IpStar (formerly called KaStar), would not have been economical. All the developers of these systems make a strong case that their spot beam systems meet the current FCC requirement to more efficiently use the spectrum.

The FCC has added this requirement since they realized that the frequency spectrum is a scarce resource. Congress in the 1980s was increasingly concerned about U.S. economic competitiveness in high technology industries. They were sensitive to areas such as satellite communication being challenged by foreign entities, where the federal government could improve U.S. competitiveness.

The Democratic Congress listened to the arguments of the U.S. commercial satellite industry in support of a flight verification program and decided it should be conducted. This debate between the Republican administration and the Democratic Congress (including each side's constituencies) over the need for the ACTS flight test continued through launch of the ACTS in September of 1993.

The Development of ACTS

Most of the ACTS technology had never before been put in space. Its development was a major technical challenge, filled with frustration, stress, and risk-taking, but offering major opportunities and rewards. It required a large government/private industry team integrating a variety of disciplines—including science, engineering, planning, finance, and human resources—to accomplish an important goal that made a real difference. In short, ACTS was being where the action is in the development and application of exciting new technologies and processes.

The keys to a successful program are no secret but bear reiteration here to point out the complexities of the job, and serve as a basis for understanding the benefits and the mistakes. Some of the main components of a successful program, according to A.

Thomas Young (former president of Lockheed Martin and center director of Goddard Space Flight Center), are:

- Finding good, experienced people
- Instilling attention to detail
- Building adequate reserves
- Avoiding political consideration
- Putting quality first

Good, Experienced People

Getting the right people on the team is what separates successful projects from those that fail. A good engineer is one who has designed something, had it built, and seen it fail. There have to be enough experienced personnel (managers, engineers, technicians, planners, etc.) on the team who will make certain that the same type of mistakes made on previous projects won't be repeated. For those who do not have the experience, proper training must be provided.

Attention to Detail

Space projects rarely fail because of large flaws. It is usually the overlooking of seemingly small details that dooms otherwise sound programs.

Adequate Reserves

Repair shops are few and far between the earth's surface and geostationary orbit. Working on an experimental program such as ACTS requires adequate margins in funding, scheduling, spacecraft performance, and so on.

Political Consideration

While every project begins with technical need, political considerations soon tempt projects to leave in other factors that will raise cost and risk. To avoid such influences, the project needs an inviolate shield around it.

Quality First

Performance tests have to be built into each step of the project. Quality cannot be balanced with other variables—it must be the top priority. In this chapter we will review the development of ACTS and provide a scorecard on how well the financial, schedule, and technical objectives were accomplished, as well as the reasons for the successes and failures. Using this process, we will see how well these key steps were implemented to achieve a successful project.

One Strike for (and Three Strikes Against) a Successful Development

Motivation is another key factor that makes a big difference in whether or not an endeavor is successful. Norman R. Augustine, former chief executive officer of Lockheed Martin nicely summed up the role that motivation plays in his book entitled "Augustine's Laws."

He stated that "Motivation makes the difference. In sports this is sometimes equated with 'mental toughness'—how else can one explain the numerous occasions each season when a team soundly beats another only to find itself thrashed by the loser a few weeks later? Motivation will almost always beat mere talent."

At the outset, there were major strikes against ACTS that were significant negative motivation factors:

- First, the federal administration never supported the program and the Office of Management and Budget (OMB) zeroed out the budget for ACTS before the development contract was awarded and during the following 4 years. These actions continuously put a negative cast over the project.
- Second, there were many people within NASA who opposed ACTS because it was not a NASA mission (i.e., it provided technology for commercial purposes only). As a result, many people within NASA considered it a low-priority project.
- Finally, there was no planned follow-on to ACTS that could be used by NASA LeRC as a carrot for getting good contractor performance. When allocating personnel resources to jobs, contractors frequently assign the best people to those jobs that will bring in repeat business at a handsome profit. For ACTS, assignment of experienced contractor personnel was a significant problem.

The major spacecraft contractors (Hughes, Ford Aerospace, RCA AstroSpace/Lockheed Martin) competed aggressively with each other for both commercial and government contracts. Hughes opposed the development of ACTS and lobbied against the development contract award to the RCA contractor team that consisted of first-tier subcontractors, TRW, and COMSAT.

This action by Hughes was actually a positive motivational factor for RCA. It served to increase the resolve of Charles Schmidt (the head of RCA AstroSpace at the time) to make ACTS successful. In the end, it was largely due to actions by Charles Schmidt that led to the successful development of the ACTS program. He placed a high value on the technology and went to bat for the program both internally and externally.

The Initial ACTS Development Contract

The NASA LeRC awarded the prime contract for the spacecraft, the master control station (MCS), and 2 years of in-orbit operations to RCA (which in time merged successively with GE, Martin Marietta, and Lockheed Martin) on August 10, 1984, for $260 M. The contractor team consisted of RCA as the system integrator and provider of the spacecraft bus, TRW as subcontractor for the communications payload, and COMSAT as subcontractor for the NASA ground station (NGS) and MCS. The $260 M did not include the cost of the shuttle launch or the booster to place the spacecraft in a transfer orbit from low-earth, shuttle altitude to geosynchronous altitude (Figure 9.3).

The cost for the launch and the PAM-A booster was not included in the prime contract.

At the time of the contract award, the LeRC cost estimate for development of the ACTS system was $329 M. This estimated cost included the prime contract, the LeRC contingency (approximately 15%), and other development costs including support for long-lead technology development. This $329 M total did not include the additional program funds levied by NASA's headquarters for taxes that occur at the agency level.

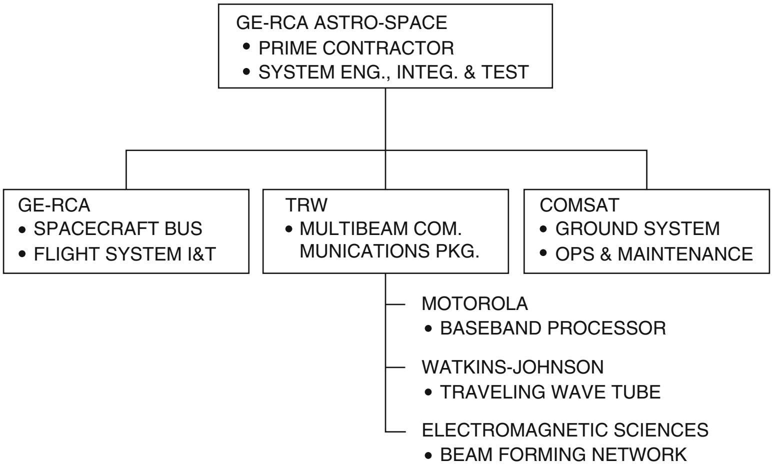

Figure 9.3. Initial contractor team for ACTS system development (1984). ("The Advanced Communications Technology Satellite" book source).

The ACTS system design, development, and launch preparation period was initially planned for 60 months, with the launch of the spacecraft projected for September of 1989. The normal commercial communication spacecraft at the time was being developed in about 3 years compared to this 5-year scenario. The extra time for ACTS was judged to be necessary to overcome new technology hurdles, to develop an extensive communications payload engineering model, and to conduct a 3-month, pre-launch systems test for checking out the complicated network between the onboard processor, the MCS, and the user terminals. The engineering model for the payload was included to remove development risk. The ground/spacecraft system test is not normally conducted when producing a commercial bent-pipe type spacecraft, but was deemed necessary for this first generation, onboard processing satellite (Figure 9.4).

Because of the high technical risk and one-of-a-kind nature of the ACTS program, the only practical procurement mechanism was a cost-plus-fee contract. Under this type of contract, the government takes on all cost risks.

Because the technology was being developed for commercial application, the fee allotted for the contractors was fixed at 5.5%, which was considerably below the 12–13% normally collected. With this fee arrangement, the contractors were, in essence, making a direct contribution toward the funding of the program.

That contribution, at the time of award of the contract, was approximately $20 M (the fee difference between the normal 13% and the ACTS contract 5.5% fee).

In addition to the lower-than-normal fee, RCA contributed approximately $2 M for the steerable antenna that was added to the spacecraft after contract award.

This steerable beam antenna proved to be a valuable addition and was extensively used during ACTS operations. All the major contractors on the team contributed their own funds to purchase terminals and/or to support the planning, solicitation, and conduct of experiments or user trials. This amounted to approximately $4–5 M more in contractor contributions.

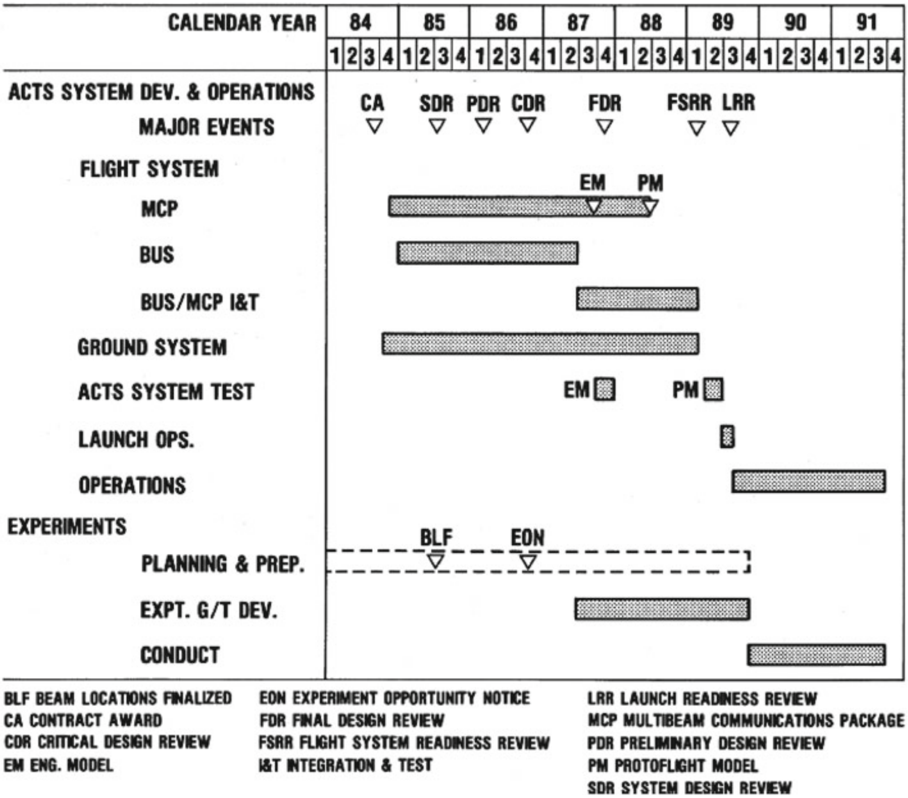

Figure 9.4. Initial ACTS development schedule. (From "The Advanced Communications Technology Satellite" book).

The ACTS Development Scorecard

At the bottom-line level, the technical, schedule, and cost performance is readily expressed:

- The launch occurred on September 12, 1993—some 4 years after the original planned date.
- NASA LeRC's cost for the program grew from \$329 to \$481 M.
- All technical objectives were met or surpassed.
- The satellite's lifetime expectancy was exceeded by more than 3 years.

Only minor spacecraft anomalies occurred, none of which decreased its communications capacity A quality product was produced at considerably more money and time than initially anticipated. Development of high-risk technology is seldom produced in less time or at a lower cost than planned. The remainder of this paragraph will discuss the primary reasons for cost growth, schedule extension, and the attainment of a quality product.

Elements of Cost Growth

Technical Changes

From the start, the LeRC project management philosophy was to write the ACTS technical requirements in terms of general functional capability, without dictating the

detailed technical approach or changing the technical requirements. This latter philosophical item meant resisting outside influence to add goodies beyond the original scope. By taking this approach, the NASA LeRC project management team hoped to ensure its integrity (by not trying to get added features for no or little increase in cost). This objective was almost completely accomplished. Over the lifetime of the program, the technical scope changes to the development contract resulted in a net reduction in cost.

Early in the development program, the contractors suggested (and NASA implemented) technical changes to reduce program costs. These included deleting a full-up engineering model for the MBA, a spare flight model BBP, and a diversity earth station. In addition, the base band processor's downlink burst rate and total throughput were cut in half and the number of spot beam locations was significantly reduced. In total, more than $25 M in technical scope was removed from ACTS.

Funding Constraints

The control of the amount of funding any program receives each year is in the hands of the NASA administrator, the federal government administration, and the U.S. Congress. The administration's OMB zeroed out funds for ACTS in its yearly budget requests to Congress in 1985 and 1987–1990. Congress was then put in the position of reinstating funding for the program over the objection of the administration. This process frequently resulted in less money being appropriated than originally planned, with a resultant slip in the development schedule and an overall increase in total project costs. The reason that total project costs grew with a stretch-out in funding is that many people (such as project controllers and system engineers) were required to remain with the project as long as it was in the development stage. Frequent reassignment of key individuals to other projects, with the loss of their knowledge and ownership, was not practical.

With the large number of subcontractors, the effort to create a new plan after each funding cut also took considerable time and effort (money).

The first time that funding was zeroed out was in December of 1983, just prior to the planned contract award. As explained in Chap. 1, "Program Formulation," the administration chose to do this when Hughes submitted their filing for their own Ka-band satellite and claimed that the NASA program was unnecessary (Hughes never followed through and actually built the spacecraft).

This OMB action caused the development contract award to be delayed 8 months—from December of 1983 until August of 1984. When the funds were finally reinstated for the project, they were done so at a lower level than the development plan required. Worse than the effect of the reduction in funding was probably the impact on contractor personnel. Many of the people who had worked on the proposal were no longer available for assignment to the project 8 months later. Therefore, new individuals who were not familiar with the project and who could not be held responsible for the proposed development plan had to be assigned. This is not the way to start a project!

Fiscal year funding constraints were imposed upon the development program four times, causing schedule stretch and increases to the total program cost. The total project cost growth due to program stretch-out was $53 M (Figure 9.5).

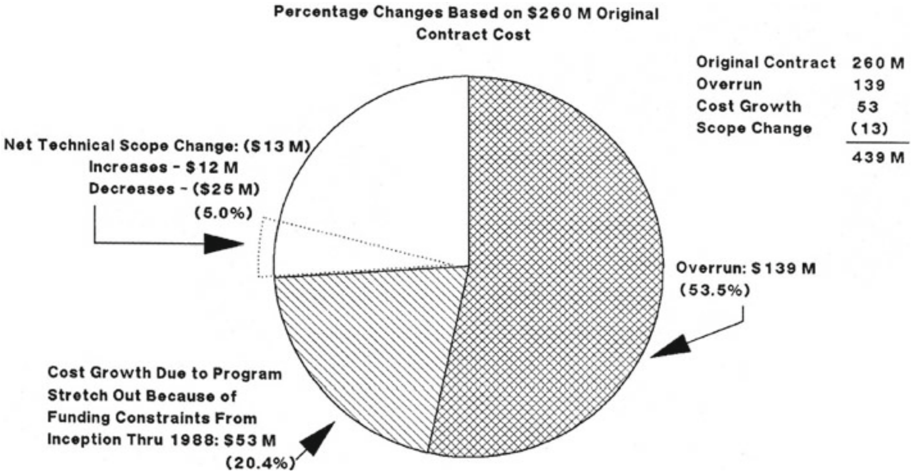

Figure 9.5. Elements of ACTS contractor cost growth as of January 1988. (From "The Advanced Communications Technology Satellite" book).

Overrun

Contractor overrun was $139 M. The overrun, which occurred mostly during the second and third years (1986 and 1987) of the development contract, was due primarily to the TRW communication payload subcontract. LeRC project management believed that one of the main reasons for TRW cost growth was that TRW and their subcontractors underestimated the true development cost in their proposal. Such underestimating has always plagued the government in cost-plus programs, and it appeared that ACTS was no exception. This was not totally the fault of the contractor. The contractors knew the government's target price for ACTS and made sure they met it in their proposals.

Another reason for the TRW overrun is believed to be the low-priority TRW placed upon the program. At the time of the ACTS contract, TRW had many classified programs that provided them with long-term revenue and profits. ACTS, being a one-of-a-kind spacecraft, appeared to have significantly lower priority than those built for military programs. Few seasoned veteran engineers and managers were assigned by TRW to the ACTS project. Having more veteran engineers on the program would have gone a long way toward eliminating many technical and management problems, with a resultant reduction in overrun.

The Capped Program

As the overrun grew, Congressional support for the program started to wane. By late 1987, it was clear that if the program was to continue, some sure way to limit cost growth was needed. The choice that satisfied Richard Mallow, the chief congressional staffer on the House appropriation committee in charge of NASA's budget, was to cap the total NASA cost for the project. This cap was to apply to all levels, including NASA headquarters, NASA LeRC's project group, and each of the development contractors. All contracts were to be changed from cost-plus into ones that were capped. Mallow desired that the ACTS program be capped at $499 M.

With 3 years of work completed, a lot of the risk associated with the ACTS development was removed or better understood. As a result, the LeRC project management felt that conversion to capped contracts was feasible. At this time, TRW had already incurred costs for approximately $153 M, and wanted $72 M more to complete the payload under a capped contract—which they were very hesitant to accept (the original contract value for the communication payload was only $106 M).

When all of the costs were received from the contractors for completing the project under capped contracts, the total exceeded the $499 M Mallow target. For this reason it became necessary to restructure the development team to realize additional savings. The program shifted from a prime contract to two associated contractors.

First, it was decided to drop TRW as the subcontractor for the communications payload and have GE AstroSpace complete the payload using TRW's second-tier subcontractors (GE projected they could finish the payload for $14 M less than TRW). The second part of the restructuring was to have NASA LeRC become the integrating contractor, with one contract with GE for the spacecraft and another contract with COMSAT for the ground segment. This eliminated considerable GE costs for managing the integration of the spacecraft and ground segment activities. Net savings were realized because NASA LeRC was able to perform the integration tasks without increasing the program staff.

With this shifting of responsibilities, the completion of ACTS development and 2 years of in-orbit operations became possible within Mallow's target of $499 M. After subtraction of the NASA headquarters' taxes, the total amount of funds available to the project office at NASA LeRC for ACTS development and the first 2 years of operations was $478 M. This amount, however, allowed NASA LeRC to hold only several million dollars for contingency purposes.

Much of the credit for saving the program must go to Charles Schmidt and the original RCA AstroSpace team members who were motivated to honor their original commitments and take on considerable risks to complete the payload development under a capped contract. The acceptance of capped contracts by GE, COMSAT, and Motorola showed their belief in the value of the ACTS technology. The conversion worked. All parties reached agreement in January 1988. In a letter from Senator William Proxmire (D-Wisconsin) and Representative Edward P. Boland (D-Massachusetts) (chairman, respectively, of the Senate and House Subcommittees on HUD-Independent Agencies) to James Fletcher, the administrator of NASA, Congress agreed to the $499 M cap and provided $76 M for both FY 1989 and 1990. From that time forward, cost growth concerns lessened and everyone turned to concentrate on the task of developing a quality product (Figure 9.6).

The capping of the program provided some measure of assurance to the development team that their funding would stabilize. One year later (in January 1989) however, OMB once again zeroed out the ACTS funding in the administration's FY 1990 budget request to Congress. Once again the Congress reinstated the funds for ACTS. This was OMB's final attempt to cancel the ACTS program.

Complexities Associated with a Large Program

When the development contract was awarded in August of 1984, the contractor team consisted of RCA as the prime, TRW and COMSATas first-tier subcontractors for the spacecraft communications payload and the ground segment, respectively.

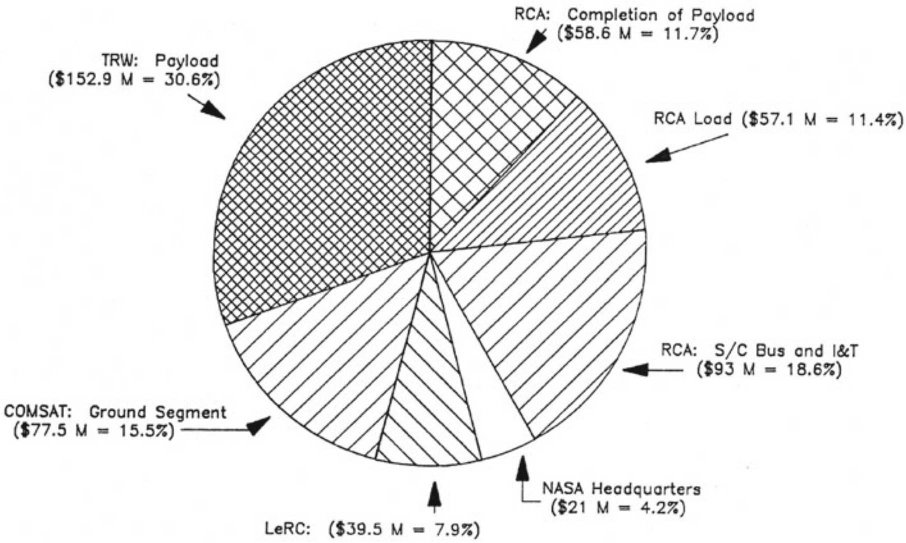

Figure 9.6. Breakdown of ACTS $499 M cost cap by organization. (From "The Advanced Communications Technology Satellite" book).

Below the first-tier subcontractors, there were approximately 15 major second-tier subcontractors. Some of the second-tier subcontractors—such as Motorola for the base band processor ($46 M), and EMS Technologies Corporation for the beam-forming network ($9 M)—were developing high-risk, advanced technology components.

For a first generation system like ACTS, layers of contractors can create major complications. For instance, TRW was awarded a definitive contract by RCA on February 25, 1985. EMS Technologies (a subcontractor for TRW) completed no substantive work on the beam-forming network until after it signed a letter contract with TRW on April 3, 1985. In August 1985, the ACTS system design review identified that EMS and TRW could not complete the multibeam antenna system, including the BFN, for the allocated budget. To reduce costs, NASA's LeRC decreased the BFN scope as recommended by the contractors.

The redefined contract between TRW and EMS was not signed until July of 1986, which was almost 2 years after the prime contract was awarded. As the above example illustrates, the process of finalizing the requirements and contracts for a new system can be very complex and time-consuming. The elimination of RCA as the prime contractor and TRW as the payload subcontractor went a long way to decrease the high degree of organizational layering (Figure 9.7).

The restructuring of the development team in 1988 was certainly a correct step for improved performance. There had been considerable friction between the prime contractor (RCA), first-tier subcontractors COMSAT and TRW, and some of the second-tier subcontractors, which made problems more difficult to resolve and contributed to schedule delays. A committee consisting of executives above the program manager level from each contractor and NASA was established to resolve top-level issues and reduce friction.

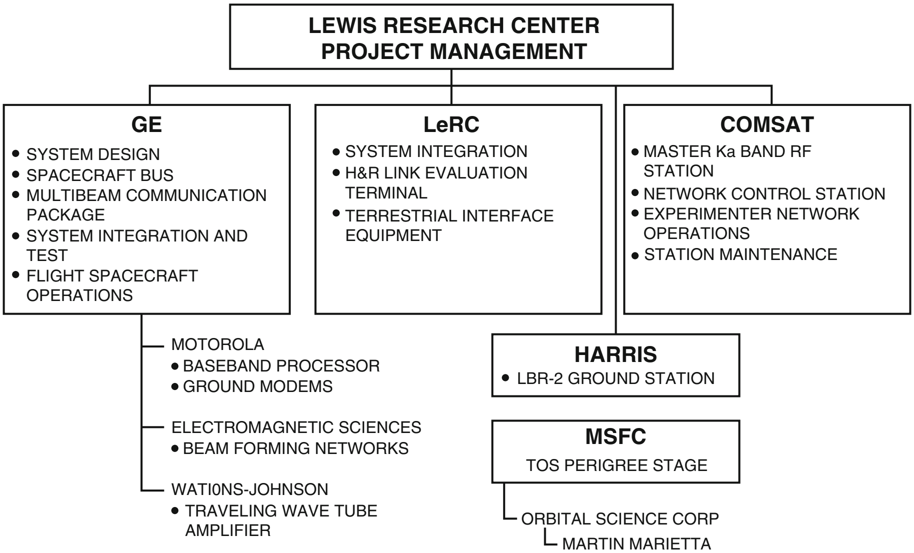

Figure 9.7. ACTS project organization after capping of the program in January of 1988. (From "The Advanced Communications Technology Satellite" book).

Even though it helped, it was not enough. When NASA took over the system integration role and, in effect, became the prime contractor, much of this friction was eliminated.

In 1988, NASA engineers took over the lead of the working groups (RF, command and telemetry, and on-demand network control) that were responsible for coordinating the interface requirements between the spacecraft and ground system. NASA promoted as rapid a technical resolution of problems as possible, and then funded any resulting contractual scope changes using its contingency funds. Use of NASA contingency funds for this purpose went a long way toward improving relations between the financially pressed contractors.

The approach that LeRC took for managing the ACTS project was to have a strong technical, cost, and schedule team that could delve closely into all aspects of the contractor activities. The ACTS project organization mirrored that of the contractor team, and monthly performance meetings were held at all major contractor facilities including those of the principal, second-tier subcontractors.

In addition, NASA project personnel participated in the standard design reviews including those for all first- and second-tier subcontractors.

The idea was to have enough in-house knowledge and expertise to perform in-depth assessment of all issues, so that the government team could make independent but practical decisions, be proactive in solving problems, and help ensure a quality product. Initially the government project team did not have all the necessary skills needed to accomplish this, but it did by the time of the restructuring and that allowed it to assume the role of integrating contractor for the ACTS system.

This role involved more than just managing the spacecraft and ground segment integration. It also included development for more than seven types of user terminals.

For each of the four times that funding constraints were imposed on the program, a 6-month process took place where funding cuts were allocated at each contractor level, new longer schedules and increased contract values were negotiated, and a new launch date was established. This whole process distracted the development team from their main tasks and consumed a large number of man-hours. It also gave the contractors an opportunity (it is the government's management job to make sure it does not happen) to get well regarding some of their own problems. One of the practices for good project management is to never take an action (such as funding cuts) that gives the contractor a reason for failing to meet development schedules.

The impact of funding constraints on a complex development program like ACTS can be disastrous. As bad as those impacts can be (on ACTS they increased the total cost by $54 M), top-level government administrators and the U.S. Congress seemed to ignore the consequences and just considered funding cuts an inevitable part of generating a yearly budget.

Completion of the Communication Payload

At the time that the program was capped in January of 1988, the flight base band processor was 85% completed by Motorola, the flight beam-forming networks were due to be delivered by EMS Technologies 2 months later, and the 20 GHz flight traveling wave tubes were completed and in test at Watkins-Johnson.

In addition, 70% of the TRW flight drawings were released and the engineering unit models had completed test. The biggest deficiency was with the mechanical design of the MBA, for which TRW had only completed 35% of the drawings.

The GE approach for completing the payload was to use the completed portions of the TRW design, making only those changes necessary to accommodate the GE manufacturing processes and test procedures or to correct design deficiencies. In addition, GE decided to use all the parts and material TRW had received. As far as completing the design of the MBA, GE felt that it was well within the capabilities of its engineers. Using this approach, GE forecast that they could complete the payload for almost $14 M less than TRW ($58 M versus $72 M).

This was how the communication payload was completed. It is TRW's initial design that was completed and manufactured by GE. To TRW's credit, they completely cooperated in the transition of all design documents and material to GE. There were many skeptics who thought GE's plan would not be successful. But Charles Schmidt, head of GE AstroSpace, had confidence that his people could pull it off!

Major Increases in Scope

At the start of ACTS development in August of 1984, the spacecraft weight at beginning of life (BOL) in-orbit was estimated to be 2,367 pounds, with 730 pounds of that total being the communication payload. A margin of 347 pounds was available for weight growth as the design matured. In addition, only enough station keeping fuel for 2 years of operations was included (Figure 9.8).

With this spacecraft weight, a payload assist module (PAM-A) was to be used to place the ACTS in the proper transfer orbit from shuttle altitude to geostationary altitude.

At launch, the final spacecraft BOL weight was approximately 3,250 pounds, with 5 years of station keeping fuel and 116 pounds of excess margin. Of this total, the communication payload weight was 1,295 pounds, including a 33-pound steerable

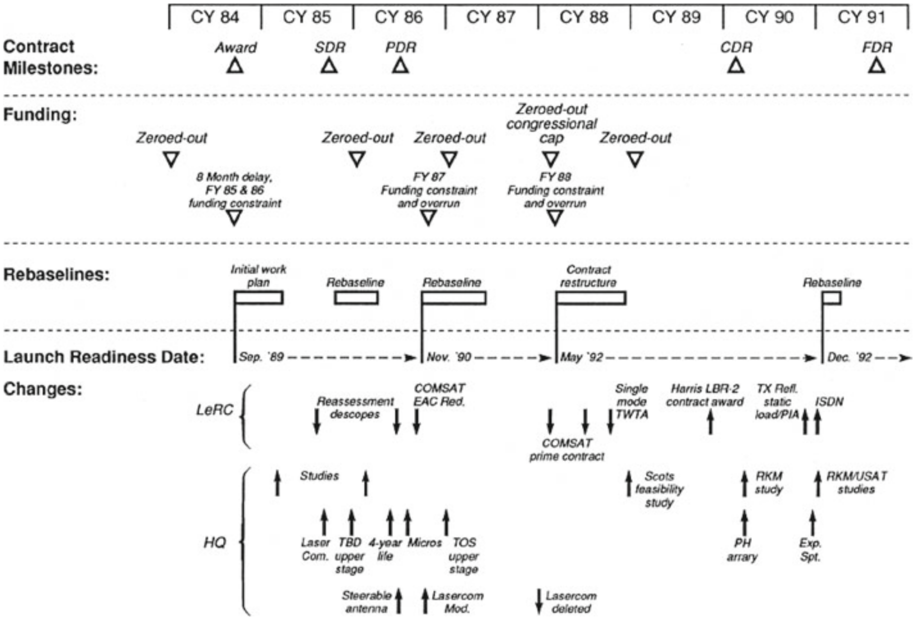

Figure 9.8. ACTS project history—rebaseline/change overview. (From "The Advanced Communications Technology Satellite" book).

beam antenna that was added in 1986. The big increase in payload weight from 1984 to 1993 was largely due to changing the antenna reflectors' stowed position during launch. The original design had the reflectors folded across the top of the spacecraft to minimize its length. This was changed to include a major truss structure on top of the spacecraft to hold the reflectors and beam-forming networks during launch.

To accommodate the 3,250-pound weight, the Orbital Sciences' Transfer Orbit Stage (TOS) was used in place of the PAM-A. The TOS stage capability was more than required and it did not carry a full, solid propellant load. The switch to the TOS upper stage was made in 1985, with the addition of the laser communications package (Lasercom). This package (which was being developed by MIT Lincoln Laboratories for the Air Force), definitely placed the ACTS weight outside the capability of the PAM-A booster.

As it turned out, after the addition of the Lasercom and the switch to the TOS was contractually completed, the Lasercom funding was cancelled by the Air Force and the package was deleted in 1987. The combined Lasercom package and TOS change was the largest single scope increase to the contract, amounting to almost $9 M. By holding the scope increases to a minimum, NASA helped to contain the project cost and risk.

Elements of ACTS Schedule Slips

The ACTS contract award was originally planned for December of 1983 with a launch in July of 1988. The actual launch occurred more than 5 years later on September 12, 1993. The combined schedule impacts due to program approval

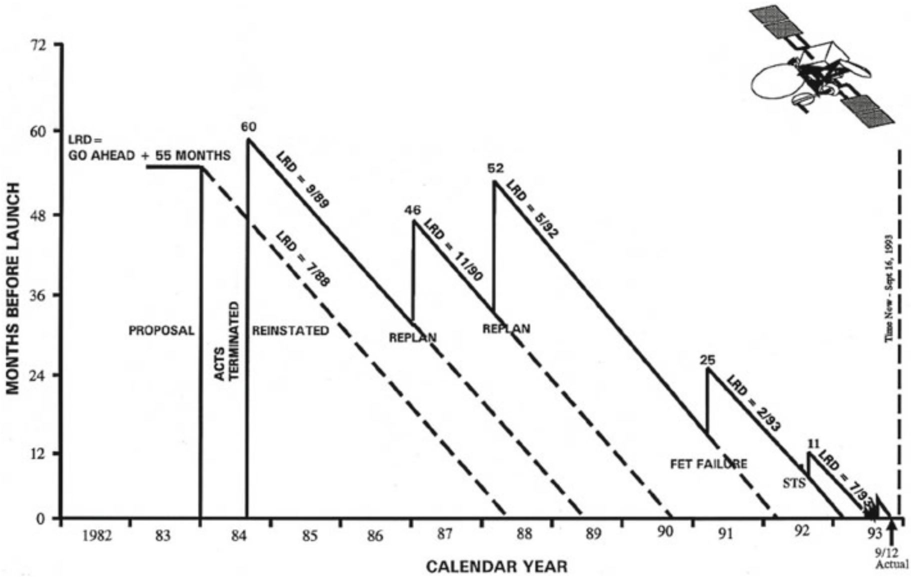

Figure 9.9. History of launch readiness date (courtesy of Rod Knight, NASA). (From "The Advanced Communications Technology Satellite" book).

delays, funding constraints, cost overruns, technical difficulties, and launch vehicle availability were gigantic. The effects of some of these factors will be discussed in more detail in this section (Figure 9.9).

Funding Constraints and Overruns

A nonadvocate review, headed by Dave Pine of NASA headquarters, evaluated the ACTS program plan in July of 1982 and concluded that a peak year funding of approximately $140 M was required to complete the 55-month development.

When ACTS development was finally started in August of 1984, peak year funding was planned to occur for two subsequent years at approximately $110 M each year, with a launch 60 months later. The maximum funds allocated to ACTS in any 1 year were $85 M. With the yearly funding for ACTS always being less than required, and cost overruns increasing the total amount of funds required, it was impossible to meet the original 60-month development schedule.

In 1986 and 1987 the launch date was slipped 14 and 18 months, respectively. Part of the slip that occurred at the end of 1987 was due to the program capping process that took considerable time to accomplish. Therefore, the funding constraints and the cost overruns were responsible for 32 months of slippage (projected launch date was moved to May of 1992) (Figure 9.10).

Technical Difficulties

When the contractor team was restructured in January of 1988, schedule margins were put in place to ensure meeting the new launch date of May 1992. As it turned out, the margins were not large enough to accommodate several technical problems and a procurement difficulty.

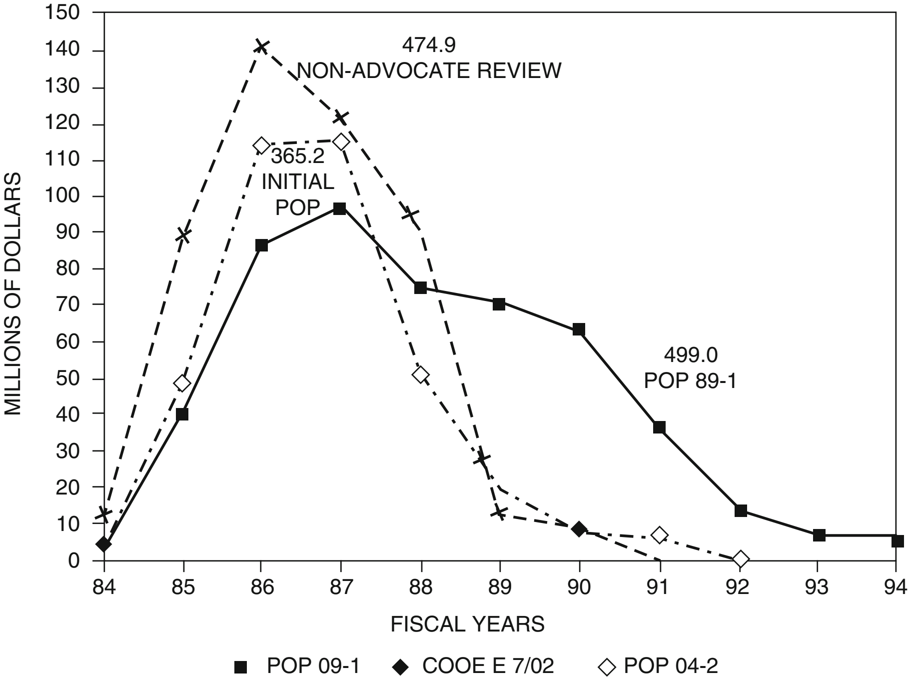

Figure 9.10. ACTS cost projections by fiscal year. Fiscal year starts October first and POP stands for Program Operating Plan. The nonadvocate review estimates were made in July 1982 by a group of independent financial and engineering experts. This group estimated a total program cost of $474.9 M. The initial POP estimates were made by the ACTS project staff at LeRC in the second half of 1984 and predicted a total cost of $365.2 M. The 89-1 POP estimates were made by the ACTS project staff at LeRC in the first half of 1989 and predicted a total cost of $499 M. This plan which "capped" the total cost using fixed-price contracts was successfully achieved. The costs in the last 2 years are for operations. Note that the nonadvocate review estimates were close to the final achieved costs. (From "The Advanced Communications Technology Satellite" book).

One of the most unexpected impacts was related to the ordering of parts by Astro Space for both the spacecraft bus and the communication payload.

For a spacecraft, part procurements represented a major activity.

First, NASA required (for quality reasons) that all electronic parts that had not been flown before be procured under Class S equivalent standards. For each new part, the procedure required the generation of a requirements document that specified a high degree of inspection and testing by the manufacturer to ensure that the part would be reliable for use in space. The requirements document for each new part had to be approved by NASA, which added time to the procurement process.

Second, the incorporation of the GE parts ordering system in place at RCA Astro Space (merger of the RCA and GE aerospace units was initiated in 1986) was still taking place and drastically slowed the process. Third, the parts ordering process for many components was not initiated on time due to management mistakes. Even though extra people were assigned to speed up the process, the end result was that the assembly of part kits for the manufacturing of electronic boxes and sub-assemblies

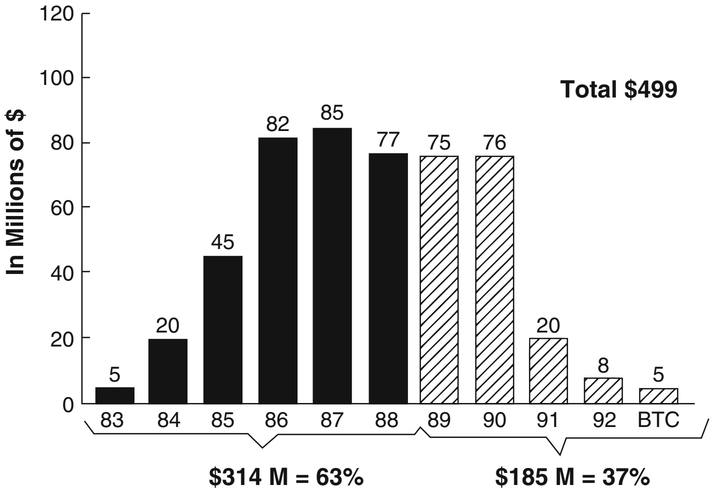

Figure 9.11. ACTS appropriations by fiscal year (January 1988). (From "The Advanced Communications Technology Satellite" book).

was significantly delayed. It took months to resolve this problem, which completely eroded schedule contingency (Figure 9.11).

A second major schedule hit was due to a problem with one critical electronic part. In any spacecraft program, one of the worst things that can happen is finding a defective part after it has been installed in boxes that have completed the lengthy manufacturing/test cycle. This disaster happened to ACTS!

Throughout many electronic boxes in the communication payload, a field effect transistor (FET) was used in many hermetically sealed amplifier modules. The laser-welded hermetic seal prevented unwanted atmospheric gas from entering the modules and causing damage by corrosion. After the many boxes that contain this FET had completed their manufacture/test cycle, it was discovered that the FET's expected life fell well short of the ACTS requirement.

Resolving this problem meant procuring new FETs, disassembling the affected boxes, breaking the laser-welded seal, installing the new FETs, and reassembling and retesting the boxes (Figure 9.12).

Delays with part ordering and the lengthy FET refurbishment, coupled with manufacturing problems encountered with the MBA were the major contributors to an additional 9-month slip in the launch date. This slip, which occurred in early 1991, extended the launch from May of 1992 to February of 1993 and was the fourth one to occur.

The final launch schedule slips were related to the unavailability of the shuttle. In September of 1992, NASA decided to expand the Atlantis shuttle refurbishment activities at Palmdale, California to include the incorporation of a docking capability with the Russian MIR space station. Although ACTS was manifested on Discovery, this caused a ripple effect in the entire shuttle manifest including the rescheduling of the ACTS launch from May of 1993 to July of 1993.

The spacecraft was delivered to NASA's Kennedy Space Center in February of 1993 to be mated with the TOS upper stage and begin final preparations for launch aboard the shuttle. The first launch attempt was made on July 17, 1993. It was

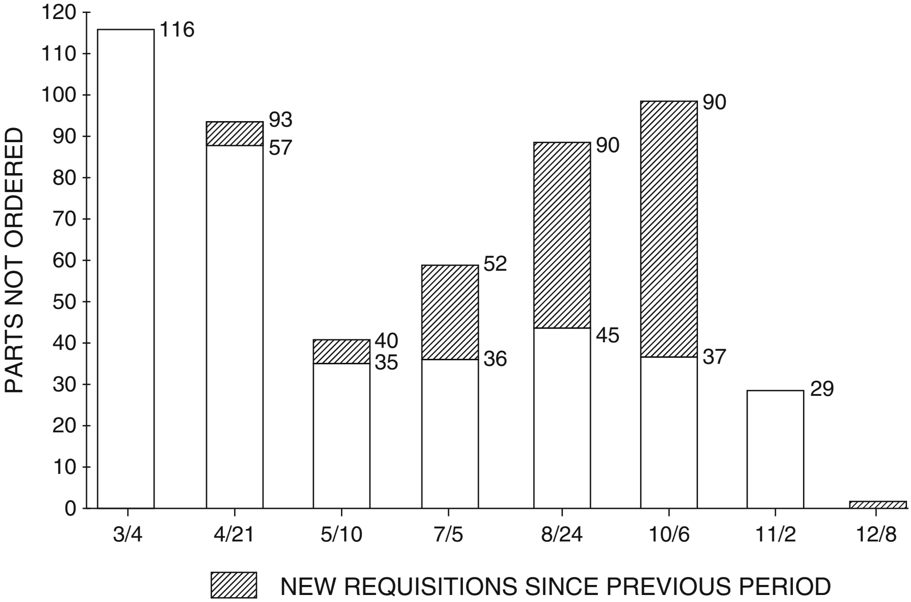

Figure 9.12. Tracking EEE part-ordering status—spacecraft bus. ("Parts Not Ordered" refers to part types, not total number of parts. Most bus EEE parts were heritage items that did not require special NASA approval to procure. Despite not having to obtain NASA's approval, it still took Astro Space more than 1 year to order the bus parts.). (From "The Advanced Communications Technology Satellite" book).

scrubbed less than an hour before the planned liftoff, due to a faulty transistor in the launch system that armed a set of explosive bolts prematurely. On July 24, a second attempt was made. It was aborted 19 sec before launch when a turbine in a shuttle auxiliary power unit (APU) did not come up to speed properly. All further launch attempts were delayed until the APU was changed and the Perseid meteor showers had passed. During the August 12th (third) launch attempt, a sensor failed to indicate that propellant was flowing and the shuttle's engines were automatically shut down 3 sec before liftoff. On September 12, 1993, at 7:45 AM EDT, ACTS was finally launched aboard shuttle Discovery on mission STS-51. ACTS arrived at its permanent location in geostationary orbit at 100 degree west longitude on September 28, 1993.

9.2. Multiple Satellite Production Programs: Risk and Organizing Principles in the OrbComm Experience

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The ultimate goal for an aerospace system Program Manager is the successful delivery of the product in its final operating state, on time and on schedule. Due to the complex technology, long duration and high cost of aerospace programs, as well as

Figure 9.13. OrbComm I satellite production line. (Photo courtesy of Orbital Science Corporation).

the inability to repair or replace satellite systems once launched and the likelihood that a failure may be catastrophic, there are a variety of risks to a successful outcome that must constantly be managed and mitigated and indeed can never be completely retired. Effective program managers build a management strategy around their approach to managing program risk, with various tactics to drive cost, schedule, design, and organizational management in support of those strategies. By basing the management of the system's development on risk as an organizing principle, technical and programmatic elements are better synchronized and reinforce each other resulting in an improved program outcome and an improved basis for decision-making along the way (Figure 9.13).

This subchapter focuses on the execution of a production program to build multiple satellites, although many of the principles outlined are applicable to many complex space systems development programs. A number of emerging space applications require the production of a series of multiple satellites, which in turn require the implementation of a satellite manufacturing line. Commercial LEO communications constellations such as Orbcomm, Globalstar, and Iridium are now replenishing their networks with their second generation of satellites in quantities ranging from 18 to 48. The Global Positioning System (GPS), Galileo and Glonass are examples of government sponsored operational constellations requiring production of dozens of satellites. Emerging applications in science and imaging call for tens and even hundreds of satellites flying in formation to collect simultaneous data points for applications such as magnetospheric mapping, continuous observation of the Earth's surface and to work together to provide sparse aperture capabilities akin to arrays of cooperative imagers in terrestrial applications (Figure 9.14).

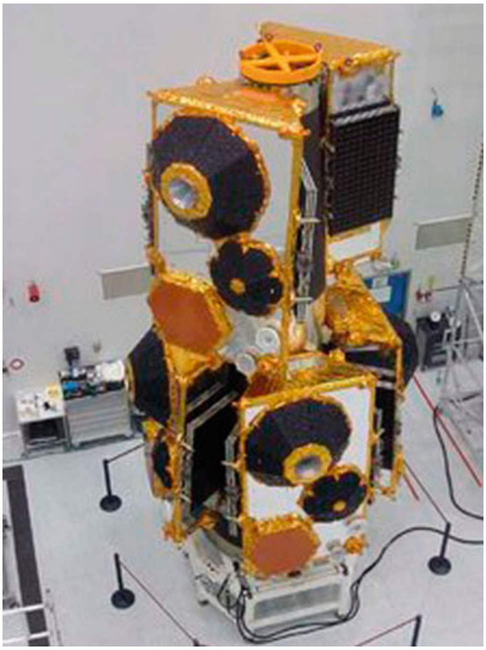

Figure 9.14. Six Globalstar spacecraft mounted on their launch vehicle adapter. (Photo courtesy of Globalstar Inc.).

Delivering an integrated system is much different from delivering a component, device, or product. The hallmark of aerospace systems is the tightly integrated nature of multiple instantiations of hardware, firmware, and software subsystems, and the requirement for them to perform together in a complex environment semiautonomously.

Therefore, the interactions between intelligent subsystems, many of which are complex systems in and of themselves, drive the focus and risks of the program into the system integration and test phase. This phase is always more complex than it appears due to unexpected interactions or interface issues between all the elements of the system. Unlike complex subsystem or component programs, which integrate system elements (hardware, firmware, software) once, a system-level program piles dozens of these complex "intelligent subsystems" together to perform some higher level function. It is critical that a program manager with a background in a component-level or product management environment not underestimate the challenges in integrating and testing this larger "system of systems" and the need to be flexible and responsive when addressing the unexpected risks or problems which may arise in the system integration and test phase.

Managing Multiple Satellite Production by Thinking About Risk

In a multiple satellite build program, it is important to remember that the goal is not a single finished, working satellite but rather an entire production run deployed on

orbit. Risks in development of the first unit of production are multiplied by the full number of satellites built. Costs in the early stages of the program must be carefully managed as the budget needs to last not just through the launch of the first satellite but the launch of the last one. Therefore, thinking about and managing risk as it is carried, transferred, and mitigated throughout the program phases is the key to success in delivering an entire production run of satellites on time, on schedule, and with high quality and performance.

Multiple satellite programs are distinct in an important manner in that the reliability of the overall system is what the ultimate user cares about rather than, strictly speaking, the reliability of any one spacecraft. Especially in small satellite or commercial constellation programs (a "constellation" being a network of identical or similar satellites that together execute a particular application) the random failure of any one satellite has a much smaller impact on the overall system than it would if the satellite were standing alone.

On the other hand, design problems or systemic issues can be catastrophic for a multiple satellite mission. A design issue or a repeated workmanship problem that causes failures has a ripple effect across the entire constellation if it affects every satellite in the group, having a very costly impact to the ultimate users of the system. Examples are the failures of S-band amplifiers on the first generation Globalstar constellation starting in 2006 which eventually took their entire global satellite telephony system out of service, and the attitude control system failures on the series of five Orbcomm Quick Launch satellites lost in 2009. Even lower level failures that cause degradation and require attention from the ground can have much more severe impacts when a small Network Operations team must continually monitor the issue in real time in 20, 30 satellites or more.

Setting the Level of Acceptable Risk for the Program

One of the first steps a program manager must take is to understand and translate the acceptable level and nature of risk at the start of the program, as this drives a variety of program strategies as well as elements such as budget, schedule, technical approaches, and the composition of the team. Understanding this level of risk is a challenging undertaking and requires not only hard engineering judgment to assess requirements such as design life, reliability, parts requirements or redundancy, but also soft skills to assess reputational risk, the assignment of risk in the contract across various parties, and the political and business context surrounding the program.

The "risk posture" of a program is defined as the overall program approach to risk, the acceptable or assumed level of risk characteristic of the program. Typically this risk posture is embedded in the program from the early days of its conception, and is communicated through the budget and schedule, the requirements, the business model if it is a commercial program, the players involved, the process through which the program became a reality, and dozens of other ways. It is not a "hard fact" but rather an inferred and implicit understanding amongst the stakeholders set in the early days of the program. It is the challenging job of the program manager to correctly assess the risk posture and then communicate it to all the actors on the program, remind the stakeholders of it when they act inconsistently, and be sensitive to adjustments and changes in the program's risk posture if they occur. It is often difficult to state the risk

posture in explicit terms, but a good program manager will translate that risk posture into a consistent decision-making approach that enables the program team and stakeholders to understand the actual versus acceptable risk and act accordingly.

Hard Indicators of Risk Posture: Program Requirements

Several hard requirements in the Statement of Work (SOW) and Technical Specification relate directly to the risk posture of the program. Reliability is typically provided as a target value per satellite using industry standard reliability calculations. This gives strong insight into the risk posture of the individual satellite, and ideally (but rarely) will be coupled with constellation-wide reliability requirement. Design life is another good indicator of risk, as a 3-year mission takes a much different approach to risk than a 15- or 18-year mission.

Requirements that drive program execution are often derived from these overarching lifetime and reliability requirements, and these constraints are often found in the formal contract Specification as well. For example, the level of redundancy required in the design may be called out in the contract Specification. Parts quality constraints and manufacturing standards to be observed should be identified in the Specification as well. Cleanliness, handling, and testing minimums are also often good indications of the risk posture of the program.

It is very important for the program manager to identify inconsistencies between the hard indicators of risk such as technical and quality process requirements and softer ones such as budget and schedule. Where there is a mismatch—usually too much reliability desired for too few dollars or days of program duration—that inconsistency must be identified, clearly communicated, and resolved immediately. This process of setting expectations—"here's what we can do for that amount of money and time"—is an essential part of a successful program. In deference to the risk involved in any aerospace program, it is always best to underpromise and overdeliver, as everything takes more time and costs more money than one believes it will in the early days when the plan looks perfect on paper.

Soft Indicators of Risk Posture: Contract, Budget, and Program Timeline

The program contract is a living document, representing a complex negotiation between human beings with desires, agendas, pressures, and personalities. It embodies the risk posture, values, and agreement between the buyer and the seller of the satellite system. A complex negotiation preceded the contract, with a complex resolution, and the contract is no more and no less than the physical record of that agreement. It details what the customer values and where the risk in the program is apportioned—who is responsible for what, and who holds the risk if and when things go wrong.

Understanding the intricacies of the contract gives a deep level of insight into the arrangement and apportionment of risk across the parties, and therefore how the Program Manager should manage the program.

A sample of questions to consider includes:

- Is it cost-plus or fixed price? A cost-plus contract puts the risk of overruns on the customer's shoulders, whereas a fixed price puts it on the vendor.
- What are the key program milestones? A program with milestones based on technical achievements may indicate a desired focus on detailed technical execution,

whereas one with on-orbit success criteria may require a focus on schedule and mission assurance at the system level.

- What sorts of things does the customer seem to care about, based on the financial terms of the contract? Performance-based financial terms (payments per image downloaded or messages transmitted) communicate a much different set of preferences than those based on reviews or hardware deliveries.
- Are there financial penalties or liquidated damages (damages to be paid out for missed milestones or delays), if so, what are they? Many times these penalties are levied on the customer's most valued elements of the program to provide maximum leverage.
- If the contract is based on established government contracting principles, are there any exceptions taken to these clauses? Unusual clauses added or removed? These can indicate a focus on a certain type of risk, or a desire to relax the risk posture and take a more aggressive approach to the program.
- Is the contract for delivery to the launch pad, or for operation on-orbit? When does the ownership of the satellite transfer from the builder to the buyer of the system? These types of clauses in the contract delineate which party is responsible for which risk elements, and who holds the risk at various phases of the program.

The program budget and timeline are also good clues to the risk posture of the program, where a tight budget or a very compressed schedule indicate that a more risky posture may be acceptable—otherwise the program manager will be unable to deliver to that budget or schedule. A contract which calls for an accelerated development schedule and minimum cost, while at the same time specifying very high reliability is an inconsistency which must be addressed immediately by the program manager.

The importance of not letting these inconsistencies fester, but rather addressing them immediately, cannot be overstated. Mismatched expectations between stakeholders is a major cause of programmatic and business problems down the road, and it is essential to have the hard discussions early on the program to get everyone aligned on risk and the program approach, rather than waiting until funds have been spent, negotiating positions hardened, and various parties have exposure to risk they did not realize was coming.

Often the Program Manager takes the blame for the problems that ensue.

In general, the Program Manager must trade performance, cost, and schedule against each other. One can usually deliver a high level of performance of two but not all three, although due to the large standing armies of staff on aerospace programs a compressed schedule can sometimes lead to a lower cost (but at the risk of burning out staff). Any buyer of a satellite system wants all three, and the Program Manager must identify areas where the trade between the three items is not achievable or only achievable at high risk. He or she must bring those issues to light with management and ultimately the customer as soon as identified rather than later in the program, when the cost to recover from problems is much higher.

Integrating Risk into Program Planning

The level of risk set by the program manager should translate into the program plan. The level of risk embedded in a satellite system will never drop to zero until the satellite is on-orbit at its end of design life and has met all its requirements at

that time. However, the program plan should identify the key risks and work to drive them down as early in the program as possible when there is still time and money to recover from unexpected problems and setbacks.

The level of risk expected in the program will drive how the program plan is put together. A higher risk profile will retain risk in the program until later stages, which will typically allow an accelerated schedule or a lower program budget, or both. A lower risk profile will attempt to drive down risk early during the design phase, as well as implement process constraints that keep risk low in later stages, but at the cost of a longer schedule or higher program cost.

Low-risk posture	**High-risk posture**
Extensive supplier quality audits and certification	Limited supplier oversight and acceptance testing
High QA and documentation requirements	Increased responsibility on individual engineers
High levels of hardware and design testing for all units	Workmanship testing only for production units
Rigorous manufacturing requirements on each unit	Requirements met via similarity or heritage
Simulation, analysis, and development of flight-like test hardware during design phase	Simulation and analysis to validate design approaches, carrying hardware risk into build phase

By incorporating risk into program planning, program managers can achieve a more favorable balance between performance, cost, and schedule.

When the program enters production, risks should be beaten down and well understood to ensure an uninterrupted production flow, thereby harnessing production efficiencies. In order to do this, it is essential to consider what the highest risk elements of the program are based on the conceptual design of the mission.

Then activities should be undertaken to drive down those risks as early in the program as feasible. If the right activities are prioritized, then those investments can identify issues early and design the implementation of the program to enable a smooth and well understood execution. This will minimize the unexpected setbacks that impact cost and schedule in the later stages of the program when there is less time to recover or when the program manager is counting on uninterrupted production flow to provide cost and schedule efficiencies.

Bid and Negotiation

In a well-executed program, the Program Manager is deeply involved in the bid & proposal and the contract negotiation phases. These are the phases during which both the soft and hard elements of risk in the contract are established, and the assignments of those risks to different players are allocated. It is important to work with the customer to talk them through these issues of risk, performance, budget, and schedule, and if possible calibrate them to an understanding of the right balance of these issues.

The proposal needs to embody these points and address the benefits of risk mitigation versus competitors who may not have thought it through and are simply claiming the lowest cost position.

The contract negotiation is a critical time to manage and set risks, because all future issues with the customer will be resolved by referencing the level of risk accepted by each party in the original contract. All the elements listed above in this subchapter are on the table during the negotiation.

One essential element is carving up the contract into risks that the Program Manager has the ability to control, and risks that he or she does not. For example, launch is generally out of the control of the Program Manager of a satellite program. If the launch fails due to a launch vehicle anomaly, there may be payment milestones attached to that event such as a payment on launch or on-orbit milestones that will never be achieved. There needs to be some mitigation of that risk in the contract in case of issues that are no fault of the vendor, or some way to cover the cost of insurance on those milestone payments. If these considerations are not made, then the vendor is effectively sharing the underlying business risk of the program activity and needs to be compensated for that in some way, perhaps by sharing in the financial returns of the activity.

In the aerospace business, one risk that can never be transferred to a customer or handled via insurance or some other means is risk to the developer's reputation. There are a small number of vendors in the aerospace community, and the heritage and experience of those vendors is established over decades of program performance. No matter how well the risks and financial impacts are mitigated in the contract, reputational risk will remain with the vendor, and some method to control that risk must be retained. These can include agreements to share pre-ship review accountability, independent internal mission assurance activities, and agreements with customers to characterize risky projects in clear and specific ways in the media and with the larger aerospace community.

Requirements

The start of the program is the requirements definition phase, and for a multiple satellite build, this phase must take into account not only just the technical performance of the desired satellite but also the requirements for manufacturing and production, and the requirements for operation of multiple satellites simultaneously by the end user.

The requirements define what the program team must accomplish technically in the program activity. This combined with the cost and schedule orients the program with respect to the level of risk that is implicitly acceptable during execution. Rigorous requirements with a great deal of process control speak to a low-risk approach, and a commensurately higher budget and longer schedule to execute the program activity. A lower level of process controls, lower budget, and short schedule for execution is an indicator of a higher tolerance for risk by the ultimate user of the system.

Repeatability is an issue not normally encountered in a single satellite build but one that is essential to consider for the development of multiple satellites.

The ability to achieve performance requirements in a repeatable way over multiple units is an important and unique consideration in a multiple satellite build. Many complex components used in a satellite system require extensive tuning or craftsmanship in order to gain the required performance of the device.

For a one-off satellite system, this may be an acceptable risk. However, for a multiple satellite build, the expected yield of a device or system is important. Expected yield is the number of compliant units expected per 100 attempts to build it. A low yield process, or one that has a high yield only with a very high cost of tuning and retries, can impact a multiple satellite build program in ways that would not impact a single satellite. This is a risk that is magnified across a multiple satellite build, so therefore one that must be mitigated wherever possible in the requirements phase of the program by limiting requirements that impact the repeatability of the spacecraft build at a reasonable cost.

Requirements that drive mission operations are another area that merit careful examination in a multiple satellite build. When operating, a satellite network has multiple satellites all being operated by a single team of operators. Therefore, autonomous operations and a well-understood command and control architecture are essential. An increased emphasis on documentation and configuration management also play into mission operations, where diagnosing anomalies on orbit becomes far more challenging when there are significant configuration differences between satellites that must be tracked.

Additional requirements may be levied on a multiple satellite build that might not exist in a one-off satellite build, related to design-for-manufacturability (DFM), design-for-testability (DFT), and ease of mechanical and electrical access to key components and interfaces on the ground to quickly recover in case a rework is required across multiple units.

DFM considerations may improve the efficiency of assembling multiple satellites in an environment where the satellite moves across stations and multiple sub-assemblies are integrated and stored en masse for efficiency. DFT considerations are especially important, including automating test scripts, rapid post-test data analysis, built-in-test routines, and ease of electrical mating and de-mating for test and diagnostic purposes.

In general, the requirements for a multiple satellite mission must be aware of the additional risks and opportunities inherent in a multiple satellite build and take care not to inadvertently drive riskier and more challenging requirements into the program. A design engineer or systems engineer not experienced on multiple satellite programs may not be thinking about production or mission operations risks, and therefore the program manager needs to ensure that these considerations are not forgotten during the requirements phase of the program. This can lead to either budget or schedule overruns or a level of risk in the program that may be unacceptable to the user (Figure 9.15).

Design

A bit of extra thinking during the design phase about the risk profile of the program and the nature of a multiple satellite build can build the foundation for either a well-conceived program without unnecessary risks or a litany of troubles later in the assembly, integration, and test phase.

The same concern about repeatability is critical during this phase.

The system designers must remember that any challenges or risks inherent in the design will be magnified multiple times throughout the production phase.

Tight tolerances, complex assemblies, inaccessible areas of the satellite, or unusual or complex production techniques may be an acceptable risk for one-off programs if the costs and complexities are well understood.

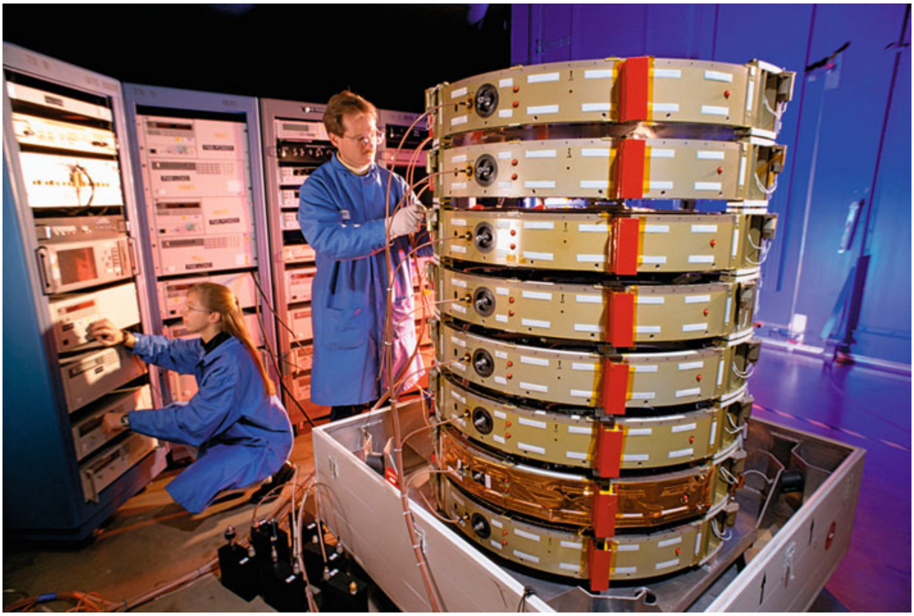

Figure 9.15. Orbcomm 1 satellites under test in parallel. (Photo courtesy of Orbital Science Corporation).

However, the multiple satellite system must be designed not only for performance but also for production.

A high performance system with limited thought put into production will drive up costs and schedule later.

More highly skilled personnel will be needed to perform the assembly later in the program. Workmanship risks carried into testing of production spacecraft will be magnified if the only way to repair them is expensive breaking of configuration to get to difficult to access areas. A longer schedule will be required to execute complex processes with low yield at either the component or the system level.

Replacement units will be expensive or even inaccessible if exotic components are used.

For a production program, it is helpful to engage the integration and test team in this phase even more than one would for a one-off satellite build.

This is the team that will have to optimize assembly and test, carry production risks, purchase fixtures and ground support equipment (GSE), and train a team of production personnel for the production run.

Their input to the design team is essential to ensure that design decisions are not made that lock the program into high risks or costs for production.

Even seemingly minor considerations such as accessibility of connectors and key components via removable side panels can make the difference between a few hours of time on the floor or days disassembling, reassembling, and managing the issues that result from breaking configuration during test.

Packaging or additional harnessing to access digital interface connectors for re-programming FPGAs and other integrated circuits is another element to consider,

so that late design or firmware changes can be integrated into production units without a significant interruption in the production flow.

The Program Manager must drive the integration of DFM and DFT considerations into the design, especially for teams that are not used to taking into account these issues.

One other program element to remember is storage. It is likely that for a multiple satellite program, a number of satellites will be launched together, and therefore the first few satellites from that shipset may need to be stored for several months, even up to a year.

Accommodation must be made for storage, including sufficient storage space and ground storage equipment so that accidents, leakage, and simply the passage of time do not damage the satellites. Critically, any components that must be highly environmentally controlled for long periods of storage such as batteries must be designed to be removed easily from the spacecraft so that as much as possible of the satellite can remain in an ambient, less rigorously controlled environment.

Early Hardware Build and Test

Even during the design phase, certain elements of the program may be identified as high risk because they use new components, never-before tried engineering approaches, new or questionable suppliers, or internally built subsystems.

In some cases, the performance requirements for the component in this program go beyond the degree to which they were tested and used in the past. Components built rather than purchased are especially risky, as they are often the result of a buy-build decision that was not able to identify an adequate market solution. In this case it is important not to miss the message the market has given, that this component may not exist because of the difficulty and cost in its realization, and thereby underestimate the complexity or risks of building it in-house. Often the satellite payload is a new or not previously built system that presents significant risk.

These risks should be identified early in the design phase and work done to build and test prototypes and to buy down risk in the early stages of the program. Above all, effort should be taken to set milestones related to risk reduction and push towards those milestones with the same aggressiveness early in the program as one would when nearing launch.

Supplier Selection and Management

In a multiple satellite build, the program manager is truly building and maintaining a supply chain that must serve the program for large number of unit builds.

He or she must invest in and tend to the supply chain to keep it healthy and intact over time. A small niche provider may be great at delivering a custom device, or offer a very low cost, but can they build 20 or 40 or 80 of them in a repeatable, consistent manner over an extended period of time, often years? An offshore provider may offer a great price, but at what long-term risks in terms of language, quality, or regulatory issues and delays?

A production run of a satellite system requires a similar production run of a variety of components and subsystems. In quantity, documentation and processes are more important than they might be with a one-off build. Each device needs to be built and

tested to the same standards for the first unit and for the last, so that the integrity of the production process at the system level is maintained. A consistent, repeatable process must be followed by the vendor.

Rigorous tracking of nonconformances, deviations, engineering design changes, etc. must be maintained and documented so that when the units are integrated into production satellites they can be managed by the production team and issues quickly identified.

Remember the goal is a production line, not '*n*' number of custom satellites.

If every component is different, every satellite will be different as well.

Early in the program, the Program Manager must set these expectations for their suppliers with visits and clear contract language. Even for experienced suppliers, a quality assurance visit early in the program and at least one visit to witness Acceptance Testing is important to at a minimum send a strong signal to supplier management that quality assurance and repeatability is important to the program. This becomes even more important with riskier or less proven suppliers in the chain.

The ability to purchase additional units later in the program, even years later, is another important consideration.

There will always be obsolescence in a design, but the goal is to limit significant design changes in follow-on purchases of production spacecraft or the need to change suppliers which will usually imply significant redesign.

A supplier with a track record of longevity that provides products that are not in the final days of their availability to the market will reduce long-term risk to the program, although usually not without a cost. In cases where a vendor presents these types of risks but offers significant cost, schedule or performance benefits, the ultimate customer can often be consulted to get their consensus and at least share the risk of any problems that may surface later.

In some cases the supplier of the best component may lack some of the rigor needed to properly execute the production build. In these cases, the program manager should consider investing in the supplier's quality systems and production capabilities via training, on-site visits, etc. Remember that when building a supply chain, the program manager is a partner with the suppliers and that one aspect of the management job is to build, support, invest in, and nourish the supply chain so that it delivers what is needed over the long term.

One way to think about the supply chain is as a repeated game. In a one-time game, there is less of an incentive to invest in suppliers, negotiate, and support their long-term health.

A multiple satellite build has a long-term, repeated element to the business interactions between parties. Investments in suppliers in a multiyear, multisatellite program can deliver great returns down the road.

This is even more important in a cost-constrained or higher risk environment, where the resources to deal with a problem supplier when it is too late to make a change in design or component may not be available.

First Unit Assembly, Integration and Test

One key element of a multiple satellite program is the need to reduce overall costs by building the majority of the satellites in a production environment rather than crafting each individual unit the way that a team might craft a single satellite for a focused science or other one-off mission.

Therefore, a first unit should be developed with a higher and more detailed level of testing and verification in order to prove the integrity of the design. Later builds on the manufacturing floor might only focus on workmanship risks and where possible assume that design risks have been retired by the first unit.

Obviously, process repeatability and consistency in parts and components across units is essential to this approach of retiring design risk on the first unit and then repeating that build with more limited testing across the rest of the constellation.

If there is not a strong level of confidence within the program team as well as with the customer that later units can be proven to meet requirements by similarity to the first proto-tested units, then this approach breaks down as does many of the promised efficiencies of production.

Design Verification and Proto-Flight

The first satellite built in the production series embodies the first ever instantiation of the design and the combination of subsystems and components that makes up the overall system.

As such, it is the testbed to validate the system design and observe how all the parts work together as a system for the first time.

The goal of the first unit should be to retire as much risk as possible from the production run. The production run, on the other hand, should be focused on lean, efficient, low risk manufacturing (Figure 9.16).

One distinction that the Program Manager and the program team must determine is between Design Verification Tests (DVTs) and Workmanship verification tests.

The distinction hinges on whether or not a particular feature or requirement can be reliably trusted to be replicated across the entire production run without verifying it on each unit produced.

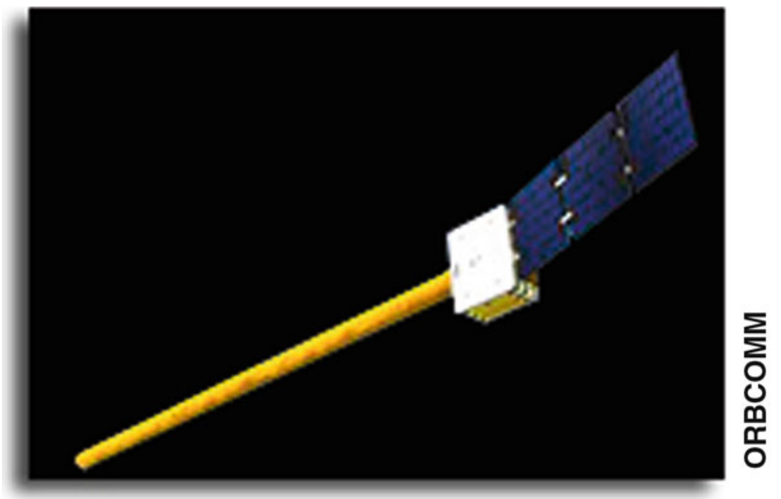

Figure 9.16. Artist's conception of the first Orbcomm II spacecraft. (Image courtesy of Sierra Nevada Space Systems).

An example is certain software features—with proper configuration control, there is no reason to believe that a particular software logic queue or telemetry point would vary from production unit to production unit.

On the other hand, the integrity of soldering joints, the proper mating of connectors, or the proper torquing of structurally critical bolts needs to be verified on each unit. These are workmanship and not DVTs.

In general, for a multiple satellite program, the first unit should undergo an exhaustive test program to validate both workmanship and design, clearing the way for future satellites on the line to undergo a more limited program.

The test suites on the first unit should not only be broader but also deeper—for example, the first unit might undergo proto-flight levels of vibration testing, 3 dB higher than any other spacecraft sees, to validate the design margin without stressing each production unit to a similar level.

Good documentation of the proto-flight first unit tests are essential, as they will form the basis for claiming compliance with requirements for all later units by similarity.

Transition to Production

The transition phase is an important phase of the program between proto-flight test of the first unit and moving to a production line for the remaining units in the lot.

While significant planning may have been done for production in the early stages of the program, there will be a number of lessons learned from development of the first spacecraft that must be integrated into the production planning.

Test procedures and processes will have been developed, difficult issues identified and solutions proven, unknown risks uncovered, and some level of reality will be placed on the duration and cost of various tasks.

All this discovered knowledge can now be applied to the “delta” planning for production and the development of tools for it.

During development of the first unit, it is inevitable that some activities were performed manually and the degree of automation must be increased to hit the cost and schedule goals of the production run.

During this transition phase, the program team should scrub the production test program, described below, for opportunities to automate testing or cut out redundant tests.

The plan for production lines must also be reviewed.

New or critical pieces of GSE that were not previously considered need to be identified and procured.

One critical lesson learned is to invest in GSE, which impacts the budget of a program manager but makes a huge difference in terms of keeping production lines going during equipment outages and keeping the standing army of staff, the highest cost for a satellite program, active and at maximum efficiency.

Depending on the number of parallel production lines envisioned, a plan for phasing the various satellites through that line and the equipment needed including scheduling for critical items such as thermal vacuum chambers and vibration tables needs to be built. Special Test Equipment (STE) needs to be identified early, and spares built

if appropriate to ensure that a line does not go down and imperil the program schedule by potentially months.

This is also the time to assess design risks that were not addressed by the first unit as envisioned in the plan.

There may be system designs or components that did not work as expected where some level of risk is being carried into the production run.

A careful assessment of these needs to be undertaken, as any deviation from the first unit imperils the ability to prove DVTs by similarity.

However, in some cases, the design simply did not work when implemented on the first unit. Some work-around may have been found, and during this transition a careful examination of whether to redesign to remove risk or to simply use the work-around on the production units needs to be undertaken.

In general, doing it "right" is less risky than the work-around option, due to the multiple unit nature of the production run and the likelihood that problems will be magnified in production. However, this is not always the case—there is also a risk of doing something new in production and that must be weighed carefully.

The timing of this transition to production is an important factor—the earlier the transition, the more open risks or questions there may be that interrupt or derail production; the later the transition, the lower the design risk for production but the longer the schedule and cost.

This is a critical decision point for the program plan, and where possible as many decisions from which there are "no return" should be delayed until risk has been beaten down.

Critical milestones such as burning one-time-programmable FPGA's or closing up and sealing inaccessible areas of the first few production units should be held off as late as possible, within reason, to allow design verification to be undertaken on the first few proto-flight units (Figure 9.17).

The risk profile of the program goes down over time. The earlier the transition to production, the higher risk during the early phases of production and the more budget and schedule margin that should be assigned to the program plan. On the other hand, the later the transition, the longer the known schedule and higher the "known" budget will be. Finding the right balance among these factors is one of the key challenges faced by the Program Manager of a multiple satellite program.

Production

By the time production begins, most risks should have been eliminated such that there is a low level of engineering risk and design risk in the program.

DVTs should have proven the design, and the first unit will hopefully have moved through a complete system integration and test program to conclusion, retiring most if not all design risk and qualifying the design with margin to proto-flight levels. At this point, the test program can be cut down to address the remaining risks—namely, manufacturing and production.

Opinions differ on how many production satellites must be completed before the majority of issues that will be seen and lessons learned have been integrated into the program. However, there is a general consensus that the program will reach this point between the fourth and the sixth units on the line.

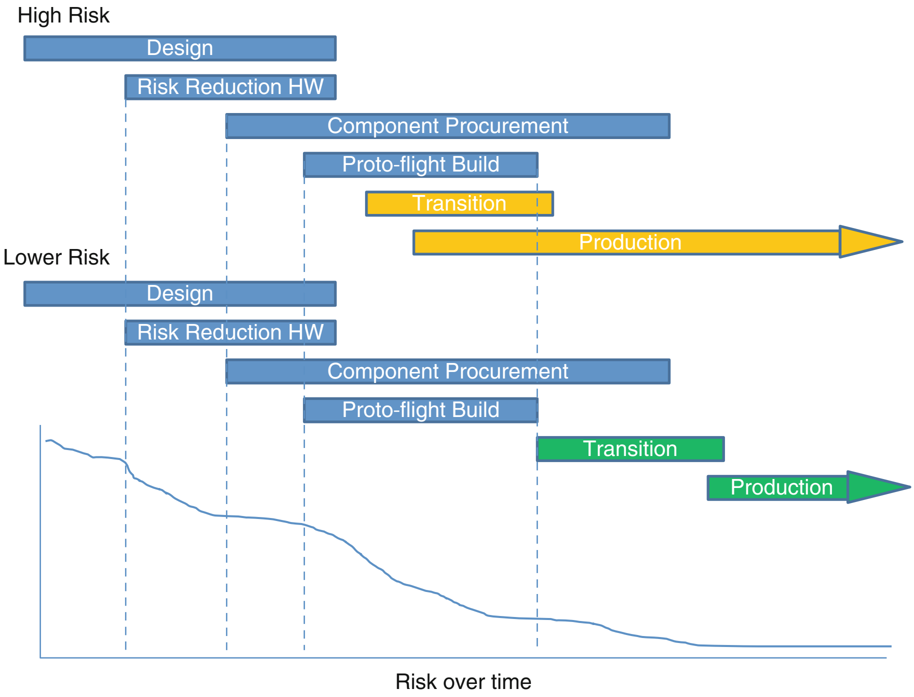

Figure 9.17. Risk scheduling. A transition to production earlier in the program carries higher risk into the production phase, but also can shorten the overall schedule for the program if the calculated risk pays off.

The first few production units will need more floor time to "get it right" than later units.

There may be a small remaining set of DVTs to validate any design changes or modification since the first unit, and these need to be built into the first few production units. Production processes are being tested and validated.

Furthermore, the full array of potential "common" issues are unlikely to have surfaced on only the first or second spacecraft—it takes running several through the process before the majority of issues that will emerge throughout the production line are witnessed and mitigation is built into the production process.

A production environment is geared to a set of repeatable manufacturing, assembly, integration and test processes that allow highly efficient manufacturing in a way that preserves the validity of the DVTs performed on the first unit in all subsequent units.

This requires a high level of repeatability in the production line and a set of documentation and process tools that ensures this repeatability.

Good QA, documentation, and nonconformance tracking are even more important in multiple production builds, as problems discovered on one system may have implications for all the satellites in the production run ("effectivity" impacts) and those effectivity implications need to be tracked and corrections verified across the production run to avoid systemic failures.

There are a set of risks that cannot be retired on each unit, related to workmanship and any design elements that are difficult to repeat. These risks must be tested for and eliminated on a unit-by-unit basis.

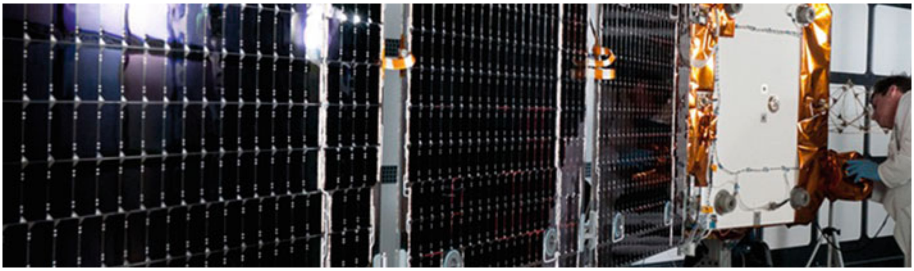

Figure 9.18. Orbcomm-2 satellite in preparation for RF testing. (Photo courtesy of Sierra Nevada Space Systems).

Component-level testing is essential to screen components, many of which will be built by different manufacturers with differing processes and quality standards.

At the system level, functional testing should be designed to check every copper path on the spacecraft. These are elements that can be affected by workmanship issues and errors. Vibration testing allows a good check of workmanship quality, as does thermal vacuum testing which stresses solder joints and the integrity of thermal pathways.

However, many DVT tests such as mission simulations can be skipped in later spacecraft—the software logic and overall spacecraft design have been verified by the first unit, so now the critical questions are:

- Is the spacecraft design the same as one that has been fully tested at the DVT level?
- Is the workmanship quality of the spacecraft good, so the design has been properly implemented on this unit?

The importance of repeatability and similarity between units cannot be overemphasized—it is the cornerstone of the production process.

Do not underestimate the impact of a "small design change" on the efficiencies of production. Any change in mission design, system engineering budgets, etc. may invalidate dozens of DVTs and require either extensive retesting or the assumption of increased risk for those affected systems (Figure 9.18).

Launch and On-Orbit Support

Mission operations are also unique for multiple satellite missions—mostly because there are often several satellites being launched simultaneously.

This means that a reasonably sized team with access to a limited number of ground stations cannot immediately control and operate all the satellites being launched.

It is essential that the satellites have a highly reliable, autonomous safe mode and that the team has developed a mission operations plan that allow each satellite to be placed into a safe mode to await its turn for initialization. This way the mission operations team can "park" the satellites and address each one in sequence.

Once deployed and operating on-orbit, it is essential to create a baseline reference for each spacecraft to catalog the differences and unique issues of each. In this manner, an on-orbit anomaly in one unit can be quickly diagnosed and addressed.

A high level of automation in this process is ideal in order to enable easier operations by a small team which otherwise will have to remember the peculiar requirements and capabilities characteristic of each element of the constellation. Notwithstanding these operational adaptations, the importance of minimizing any differences between satellites is apparent when considering the operation of 20, 30, or more spacecraft simultaneously.

It is important early in the program to design an approach to "test as you fly"—using the same version and implementation of flight control software that will be used on orbit at the satellite integrator, the bus provider, and the payload provider for testing.

This way at every step operational risk is being reduced, rather than realizing late in the program that there is a disjointed requirements verification plan that verifies requirements but possibly not in the manner they will be used on orbit, which introduces further risks.

Configuration Creep and Introduction of New Products

Inherent in the concept of repeatability is the concept of "sameness."

Where any spacecraft design deviates from the base configuration, an additional complexity is introduced.

This may not be immediately apparent—perhaps the requirements are relaxed for the first few spacecraft for schedule reasons, or some additional feature is added to a set of spacecraft to accommodate a new insertion orbit or launch vehicle.

These may seem at first like changes that have a limited impact or even make the program simpler—relaxing requirements would reduce costs in a single spacecraft environment.

In a multiple satellite build program, efficiencies are gained by the number of identical systems run off the production line.

Therefore, any deviation from the base configuration is a new product that needs to be supported. With this new product comes a new set of DVTs and a breakdown in the similarity between units that allow a reduced level of testing in the production environment.

Team Composition and Organization

A multiple satellite build program has more program stages than a typical one-off development activity. The production phase looms large and that must be taken into account in the staffing plan for the program.

In general, a one-off small satellite program uses the same core team to design, build, and test the system, with some exceptions.

This can be done with a multiple satellite production program, but many efficiencies are difficult to achieve in this scenario.

In an ideal situation, the program transitions from an engineering to a production environment around the fourth to sixth unit to come off the production line.

The majority of the team at this point may be comprised of I&T technicians and engineers, with a lower cost basis than the earlier team composed of design engineers and mission architects.

It is important to have a plan for the design team to transition, otherwise it will be difficult to effect the transition successfully.

The production team should be well organized and integrated with the design team in the early stage of the program to make the transition seamless.

They will require significant training and familiarization with the design so that testing and problem resolution can be performed smoothly and with an understanding of the intricacies of the design.

The temptation to use engineers who “know the system well” should be resisted, and the program should early on transfer test knowledge to test technicians and operators who will support the program through production.

Schedule Management

The program is fundamentally split into a first article effort and a production effort.

In the production effort, it is critical to manage schedule tightly.

An elongated schedule with delays in a given spacecraft has spill-over effects on the other production units to follow.

This in turn can have significant budget implications to keep the staff on the program longer, as well as launch implications as launch readiness is dependent on multiple satellites being ready to fly.

While during the first article DVT phase getting it “right” and pushing down risk is key, during the production phase it is critical to remain on schedule and not to be “penny-wise, pound foolish” and try to save money in ways that elongate the production schedule and keep the standing army of staff and resources engaged longer than necessary.

9.3. Management of Medium-Sized US Space Programs for DoD

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To characterize the programs in this chapter as “mid-sized” is essentially comparative, as many would consider them to be small programs relative to the multibillion dollar space capabilities that are still the norm in many government and international markets.

However, they are distinct from the small programs discussed in the section on microspacecraft in so many respects that they constitute a mission class distinct from both extremes.

Medium-sized space programs are defined in this chapter to be single- or multiple-spacecraft development programs with total contract values in the range US $50–$150 M.

This value includes the total integrated spacecraft and payload, but typically does not include launch.

For US Government customers, applications are often technology demonstration or pathfinding missions, with lifetimes in the 5-year or less range.

Total mass is typically 500 kg or less to enable launch on small launchers or as secondary payloads, and the architectures are typically single-string with some

redundancy targeted at mission critical items. The customer often acts as overall mission integrator, and separately procures the instrument(s) or payloads, spacecraft bus, launcher, and mission operations capability.

The customer may contract the bus provider to integrate the instruments/payloads, or may perform that integration in-house with contractor support.

While still generally labeled "small satellites," and often launched as secondary payloads or as multiple payloads on larger launch vehicles, a mid-sized program's level of technical, organizational, and contractual complexity drives an approach to program management that is more formalized than discussed in the chapter on microsatellites.

While some of the practices characteristic of very small programs may be adapted to these larger programs, customer requirements and sometimes unwritten expectations, as well as the sheer size and number of people and of teams involved, drive different management methodologies while still striving for the overall goal of maintaining the high efficiency and low cost that make smaller missions attractive.

Many missions in this category are conducted by the US DOD's Space Test Program (STP) Office located at Kirtland Air Force Base, NASA's Small Explorer (SMEX) missions, plus agency-specific missions like the TacSats developed for the Operationally Responsive Space (ORS) Office, and the Joint Milliarcsecond Pathfinder Survey (JMAPS) mission sponsored by the US Navy. Commercial examples include the ongoing Orbcomm second-generation spacecraft program and many privately developed commercial remote-sensing missions.

Every program is unique, but the management approaches discussed herein apply throughout the category. Government agencies which employ this approach include the Naval Research Laboratory (NRL, Washington, DC), and the NASA Ames Research Center, as both have a history of developing this class of system. Contractors with proven track records of success using this kind of management approach include Orbital Sciences Corporation, Ball Aerospace, and Sierra Nevada Corporation.

Organizing the Work Breakdown Structure

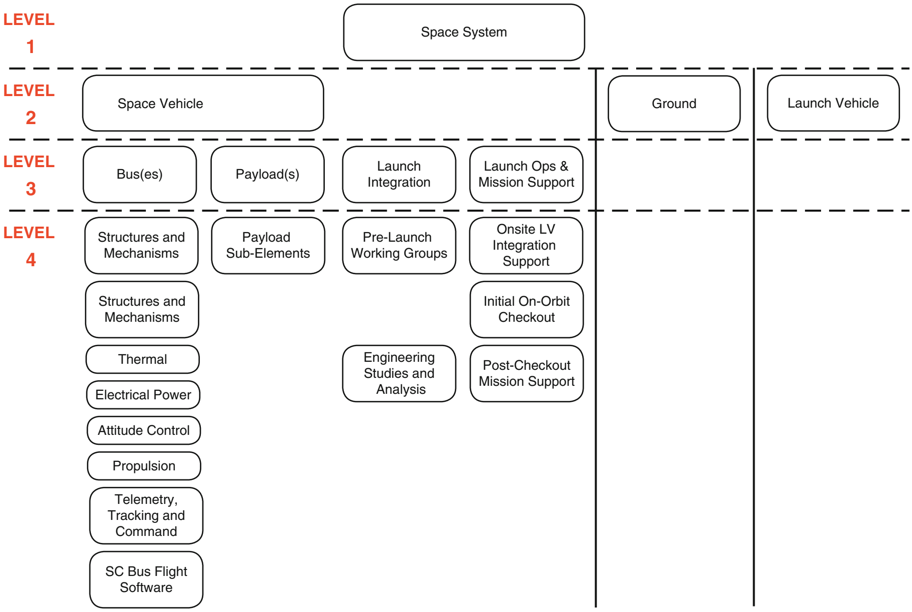
Once the space mission's top-level objectives are defined, the next major step in the management process is generation of the Work Breakdown Structure (WBS), which defines the top-level elements that comprise the program. For US Government programs, the primary reference document for defining WBS structures is MIL-HDBK-881A, *WBS Structures for Defense Materiel Items*, particularly *Appendix F: Space Systems* (http://www.acq.osd.mil/pm/currentpolicy/wbs/MIL_HDBK881A/MILHDBK881A/WebHelp3/MILHDBK881A.htm).

Per that document, the WBS "provides a consistent and visible framework for defense materiel items and contracts within a program."

The WBS is a product-focused structure for organizing and defining the work associated with a Mission or Contract. It lists every major deliverable element of a program, with those major elements divided into sub-elements.

The elements, sub-elements, and products within those sub-elements are assigned a hierarchical code.

The corresponding document to the WBS is the WBS Dictionary, which clearly explains the products, activities, tasks, and/or deliverables for every line item of the WBS.



This WBS example illustrates a typical space mission product hierarchy, with Level 4 detail provided for the space vehicle.

Figure 9.19. WBS example.

If the WBS structure is not explicitly dictated by the customer, a contractor may utilize its own WBS to capture and organize the work required by the contract.

Many organizations have created their own "standard" WBS structure, which they use repeatedly on similar programs—enabling them to compare the dollars required to accomplish specific tasks from one program to the next.

This is particularly useful when proposing new work; referring back to a previous similar program with a direct comparison of similar work is by far the preferred justification for any Basis of Estimate (BOE) (Figure 9.19).

The WBS ultimately provides the basis for the complete integrated Cost, Schedule, and Technical Performance reporting system as well as Risk Management.

All other management elements should clearly link to the WBS, including the Integrated Master Schedule and Integrated Management Plan (IMS/IMP) and the Earned Value reporting structure. The IMS, ideally, replicates the WBS structure and assigns durations to each lowest-level task or activity, which again roll up to support delivery of major program items, assigns resources to those tasks, identifies dependencies between the tasks, and links them to major program milestones.

A program-level IMS will also identify "giver/receiver" items—for example, if the bus supplier needs a payload simulator in order to complete software development and verify electrical interfaces, the payload provider would be the "giver" of that simulator at the necessary point in the schedule, while the bus contractor would be the "receiver."

It is critical to clearly identify these relationships where they exist, with clear expectations of schedule between the parties.

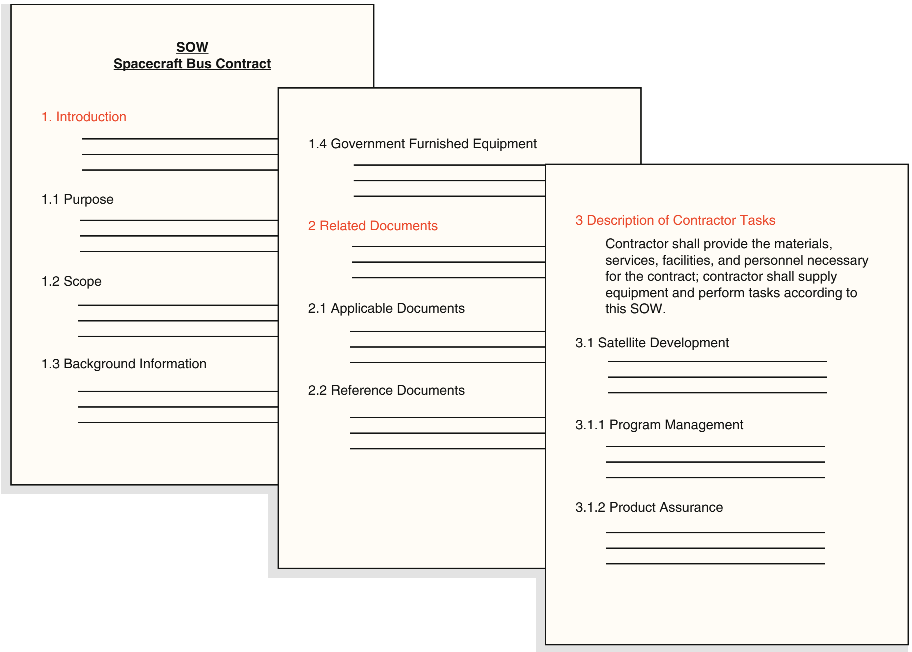
There are typically three major elements of a space mission—the Space Segment [with one or more space vehicles comprised of Bus(es) and Payload(s)], the Launch Vehicle (LV), and the Ground Segment which accomplishes all mission operations functions. Each one of these elements may be separately contracted, each with their own supporting Contract WBS. Once the program WBS is developed and an acquisition strategy is finalized, attention shifts to development of the Statements of Work (SOWs).

Schemes for the Statement of Work

The SOW for the Space Segment defines the scope of work to be performed under the contract effort, and clearly defines the end products—normally an integrated spacecraft or multiples of that vehicle and associated analyses and documentation, plus all required support activities including launch support and on-orbit support.

It is one key document that is typically part of a complete RFP that is issued by a customer, and the one that most clearly defines the management requirements for a given program. In mid-sized programs, particularly those acquired using US government "acquisition-reform" principles, the SOW is often under 50 pages and strives to define key deliverables without unnecessarily overdefining the processes used to create them (Figure 9.20).

As in smaller programs, a SOW (and other RFP documents) is ideally the result of a close collaboration between the customer and the contractor community.



The contract SOW provides program background and defines the specific tasks to be performed under the contract.

Figure 9.20. The contract SoW.

This collaboration is usually accomplished by a series of Briefings for Industry (BFIs) and customer Requests for Information (RFIs), where contractors respond with information to help structure the program contractual approach and technical requirements, and/or customer releases of draft RFP documents prior to the final RFP—either to the entire community or to a set of contractors who have indicated an interest in bidding.

A winning strategy always includes responding to these opportunities to create a program scenario that is favorable to your solution and to acquaint the customer with the key and novel elements of the solution to be proposed. After award selection, but prior to final contract signing, other changes to the SOW may be negotiated between customer and contractor to meet the target price and establish the program baseline.

It is critical that all parties have a clear understanding of the scope of work for any program, and that general terms like "launch support" or "mission operations support" are clearly defined—by some combination of schedule, headcount, and/or associated specific tasks. At a minimum, the contractor must be very specific about what was assumed and bid in the original proposal, so that any future scope changes are not subject to debate.

Referenced Documents

A SOW may provide a list of both compliance documents and reference documents, usually comprised of MIL-STDs, Handbooks, NASA or ESA standards, or similar documents.

These documents define technical and managerial paradigms for tasks like environmental testing, safety, reliability, parts quality, failure analyses, and a huge variety of other related space processes.

In a mid-sized class of program, the goal is to ruthlessly minimize the number of true compliance documents (or at least agree to negotiate their extent and content to a level appropriate to the program complexity), and instead provide that documentation list strictly as guidelines or references—and even then, severely limit it to only those that are most critical to achieving program goals.

In general, the more referenced documents in the SOW, the higher the program cost, as even the process of reviewing the list and determining appropriate tailoring is time- and resource-intensive. The philosophy for how rigorously these documents are applied is one of the key paradigms to establish between customer and contractor in the program, as there can be large and often unrecognized differences in expectations between organizations.

What is "typical" for one organization may be considered completely out-of-scope by another.

Applying Earned Value Management

If a US government contract exceeds $20 M in value, the contractor is required to utilize an earned value management system (EVMS) to baseline and track program progress.

Waivers to this requirement are possible but difficult to obtain.

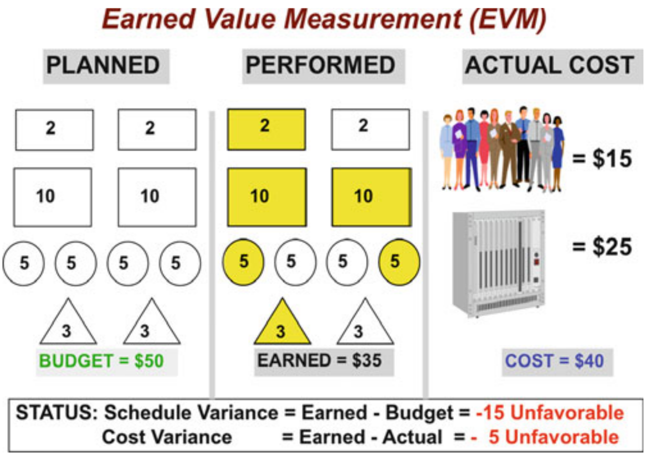


Figure 9.21. Earned value methodologies provide a quantitative measure of program progress, and are uniformly applied to mid-sized Government space programs. (courtesy from Jim Ramsey, PCI Systems formerly AeroAstro).

As with any program tracking system, the "garbage in, garbage out" rule applies—without a solid program baseline (cost, schedule, performance metrics) to track against, and the input of meaningful, relevant monthly data in the correct structure and format, the resulting reports are almost meaningless and can be no more than a waste of time and money for all parties.

In an earned value management application to a program, the WBS structure again forms the basis and structure for establishing a program baseline and tracking progress against it—providing a quantitative method for determining if the various elements that form a program are performing as expected.

This process occurs by accomplishing work that has specific dollar value associated with it, and comparing that against the "plan," or program cost baseline, on a regular basis, normally monthly. Variances between work that has been performed versus the baseline plan are identified and discussed in monthly reports; large variances are generally undesirable and the customer expects the contractor to take action to correct them.

A simplistic example of this principle, including the calculation of Schedule and Cost Variances, is provided in Figure 9.21.

The level at which variances are reported against the plan is typically at the "Control Account" level, while actual charge numbers are normally assigned one level below that, the "Work Package" level.

A key tenet of EVM is the delegation of budget authority to the Control Account Managers, who are responsible for managing their Control Accounts—essentially a mini-program within a program. Engineers are often assigned as Control Account managers, and staff training is essential if the organization or team lacks experience.

The DoD's top-level implementation guide for EVMS can be found at http://guidebook.dcma.mil/79/EVMIG.doc, though there are a myriad of related documents, web sites, and companies who specialize in applying EVM and training your staff in its application.

Many mid-sized programs attempt an "EV-Lite" approach to earned value, where the number of Control Accounts and Work Packages is kept relatively small, and they are organized to minimize management cost and overhead while still providing meaningful data that can be used to identify and tackle program risk areas.

Keep in mind that the purpose of an EV management approach, like any program tracking tool, is to proactively identify program issues before they escalate into significant problems.

The inherent delay in monthly data reporting (usually the lag between a company's monthly financial closing date, the time to perform data and variance analysis, and the actual EV report creation—on the order of 15–20 days after monthly close) can make this challenging, and a good Program Manager and Engineering Team's instincts are a more timely guide.

Ideally, the monthly EV data will simply confirm what the management team already knows about their risk areas, and provide a mechanism for applying program dollars (usually in the form of management reserve) to the problem—if dollars are needed to solve it.

Although an EVMS system reports data in terms of dollars, and the ratios calculated from the dollar values of work, remember that solving program issues does not always involve applying money. Management response may take the form of personnel actions (adding, deleting, or changing the roles of staff), reprioritizing work, creating a tiger team to address the issue (which can be very effective, particularly if you include the customer on that team) or a myriad of other potential management actions.

A key to success here is keeping your customer informed when you have a challenge. It can be tempting to stay silent on such issues, but it is almost always preferable to proactively keep your customer informed—indicating your understanding of the issue and laying out a plan to address the problem.

Customer confidence is bolstered not so much by perfect execution, but by the idea that your management team can capably handle the program challenges that inevitably arise.

Program Schedule Development

As previously discussed, a mid-sized program schedule should be developed utilizing the established WBS structure and adding information on durations, resources, and task interdependencies.

Developing and managing a complex program schedule may often require a trained scheduler who collects and integrates schedule input from the management and engineering teams—but ultimately the Program Manager is responsible for reviewing and executing the program schedule.

Overall durations of mid-sized programs (from contract start to launch) may range from a minimum of about 2 years (in the case of little or no new technology development) to 5 years or more depending on a variety of factors, not the least of which is funding stability. Durations of less than 2 years are possible if long-lead items—which can sometimes take 18 months or more to deliver—are ordered ahead of contract start or immediately upon signing.

The spacecraft contractor often winds up maintaining the mission-level master schedule, including payload inputs, launch vehicle and mission operations preparation milestones,

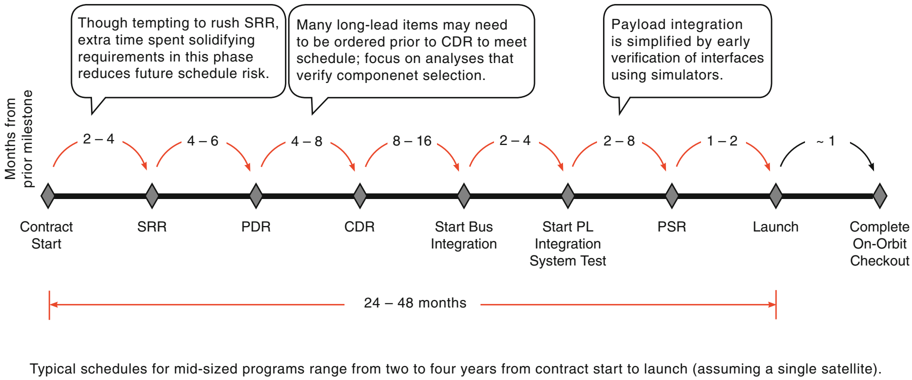


Figure 9.22. Schedule example.

and major giver/receiver relationships—even if that contractor is not responsible for every one of those elements. Anticipating this probability, and budgeting for the time necessary to keep that schedule updated, is important even in the proposal phase.

A logical, complete, and well-maintained master schedule will accurately identify both the primary and secondary critical paths, and enable management visibility and focus on the key tasks, resources, and interdependencies that support it.

Figure 9.22 presents an example of a "typical" mid-sized program schedule including ranges between major milestones—again dependent on specific program requirements and risks.

The Space Program Organization

Structuring a space program organization can be complicated by a variety of factors, including the number of stakeholders involved, their contractual relationships (or lack thereof), and the degree of new technology development required for a given mission.

If a mission is primarily a rebuild or slight modification of a previous mission with a single prime contractor providing a complete space vehicle and launch, the program organization may be quite simple, with a classic hierarchical structure of prime (with several subcontractors) reporting to customer.

However, if significant, higher risk development of certain elements is necessary, and if there are many diverse providers and stakeholders, the program organization must enable appropriate participation and access for all the stakeholders—as well as very clear lines of responsibility and authority (Figure 9.23).

A mid-sized program team, particularly one with a US Government customer, is typically organized into Integrated Product Teams (IPTs) or Integrated Product Development Teams (IPDTs).

The US DOD's Integrated Product and Process Development (IPPD) Handbook issued by the Office of the Undersecretary of Defense (Acquisition and Technology) (https://acc.dau.mil/CommunityBrowser.aspx?id=106001) most succinctly defines this process and organizational approach as follows:

> A management technique that simultaneously integrates all essential acquisition activities through the use of multidisciplinary teams to optimize the design, manufacturing and supportability processes. IPPD facilitates meeting cost and performance objectives from product concept through

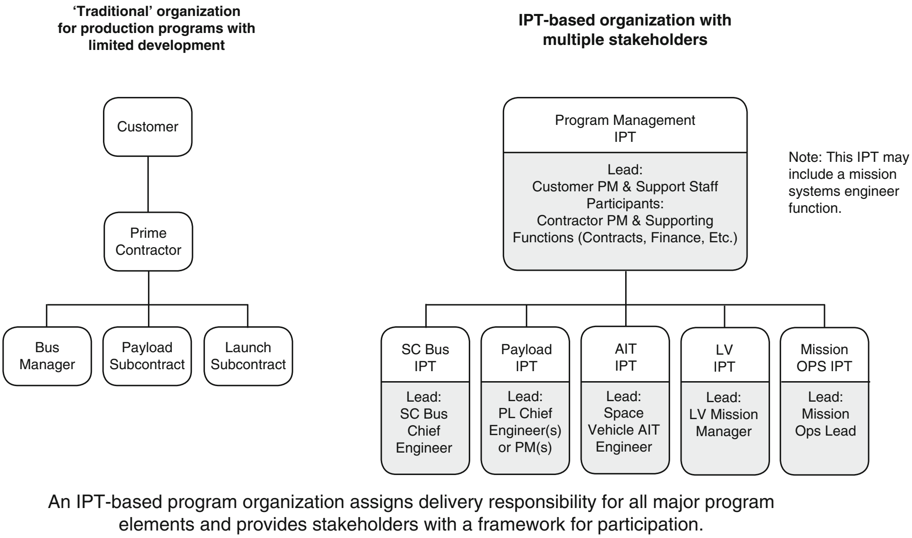


Figure 9.23. An IPT-based organization.

production, including field support. One of the key IPPD tenets is multidisciplinary teamwork through Integrated Product Teams (IPTs).

An IPT is essentially a team of people—often from more than one organization—who are responsible for successfully delivering a major part of a program—like the spacecraft bus, the experiment(s) or payload(s), launch vehicle, and mission operations function.

It provides a mechanism for many different organizations—including organizations that are often used by customers to oversee contractor activity—to participate in the development of a particular item. It is not, however, a design-by-committee exercise.

The organization chartered with the final product delivery has ultimate authority, within customer and contractual constraints. An IPT usually has a single lead individual, from the organization that is under contract for that deliverable, who organizes the team, runs regular meetings, tracks action items, and interfaces with program management to provide status.

A Program Management IPT—which may or may not include a mission system engineering (SE) element (resulting in a combined PM/SE IPT)—is usually comprised of the customer Program Manager (PM) and the prime contractor's Program Manager staff, and may include other members who provide management support functions.

The Program Manager IPT oversees the other IPTs and typically controls the overall program risk management process.

Smooth functioning of the program management team demands competent execution of all three primary management functions:

- Program Management Executive (retains responsibility and authority for successful program execution; serves as primary customer interface)
- Engineering Lead (may also be called Chief Engineer or Chief System Engineer; responsible for leading the totality of technical activities including design, analyses, assembly, integration and test, and on-orbit checkout)

- Business Support (an umbrella term for Contracts, Program Control, Procurement, etc.)

Underperformance in any one of these areas will vastly affect overall program execution, so it is critical to staff these key positions with experienced personnel with demonstrated capabilities.

It can be tempting to use more junior staff in key positions to reduce cost; while this approach can work with highly motivated, well-mentored individuals, it can sometimes backfire with schedule delays (and increased costs) created by technical mistakes and work that must be redone, as well as eroding customer confidence.

Please note that the previous comment applies only to key, senior positions on the program. In general, it is highly desirable to have a diverse mix of seniority—from junior engineers to highly experienced principals with many programs to their credit—contributing to a program's execution. Ideally, the more experienced staff provides tasking, mentoring, support, and oversight to the more junior individuals, who actually perform significant portions of engineering analyses and development, may author much of the technical documentation, and perhaps most importantly, bring fresh perspective and current tools to the work.

Judicious management of this skill mix may result in lower program costs (by utilizing cheaper resources for many tasks), while still ensuring the quality of the work—and accomplishing the parallel goal of transferring knowledge to the next generation of space engineers.

The small, self-contained structure and operation of each IPT may allow it to be managed with the star structure discussed in the microsatellite management section, where the IPT lead maintains proactive communication with all the IPT participants.

The IPT lead usually determines the communication paradigms—frequency of meetings, etc., which may vary depending on the phase of the program.

For example, the Mission Operations or Ground System IPT may meet less frequently during the very early phases of a program, but may meet more frequently as launch and operations preparations accelerate. IPTs may also be combined at some point—the Bus and Payload IPTs may combine into the "I&T" IPT after the payload is delivered and integrated with the bus.

The internal structure of the Bus IPT bears further discussion, as the size of that team alone may drive a more traditional hierarchy. In this author's experience, a mid-sized program has a core engineering team of 15–25 individuals, supplemented by additional specialists at various phases of the program.

Production and I&T staff are typically added at the post-CDR point to perform detailed planning and execution of the subsequent phases, swelling the bus team to 40 or more as the design team finalizes design documents and analyses, overlapping with the subsequent phases.

In this case, the program Chief Engineer leads the system engineering team, with the various subsystem leads (Power, Attitude Control, Command and Data Handling, Structure/Mechanical, Software, etc.) reporting to the Chief Engineer.

Depending on the degree of in-house development (versus procurement) of a given subsystem, that subsystem team may number one to five or more individuals.

Program support functions like Program Control (cost and schedule tracking), Contracts, Subcontracts, and Purchasing/Procurement are often assigned as an indirect report to the Program Manager from a matrix structure within the company.

The Mission Assurance or Quality function also almost always maintains a separate reporting chain outside the program to executive levels, to ensure that function's unbiased oversight without being unduly influenced or overruled by a program's cost or schedule pressures (elevating any areas of contention to higher levels).

A top-level IPT structure is equally effective for commercial programs though may be somewhat less formal.

The ongoing second-generation Orbcomm (OG2) spacecraft program, with prime contractor Sierra Nevada Corporation, is utilizing such a structure at this writing, with IPTs designated for bus, payload, and launch (this topic is discussed in more detail in the section on multiple satellite programs).

Although launch for the first 18 OG2 spacecraft is being provided by SpaceX under direct contract to Orbcomm, the LV IPT within the spacecraft organizational structure ensures there is a single clear interface to the LV contractor, and that various spacecraft technical leads (structure, thermal, software, etc.) can be called by the IPT lead to support LV interface issues as required.

It is important to note that the bus/payload IPTs—sometimes as a combined entity—continue through the entire mission life cycle including support for on-orbit operations.

To the degree that the technical leads can be kept available (though obviously no longer assigned full-time to the program) for purposes of periodic telemetry evaluation, and on-call on-orbit anomaly resolution support, such continuity greatly enhances the probability of long-term mission success.

Tri-Service eXperiments-5 (TSX-5) Mission Case Study

The Tri-Service Experiments-5 mission (TSX-5), developed for the DoD's STP in the late 1990s and launched in June 2000, provides a good example of this kind of program organization (Figure 9.24).

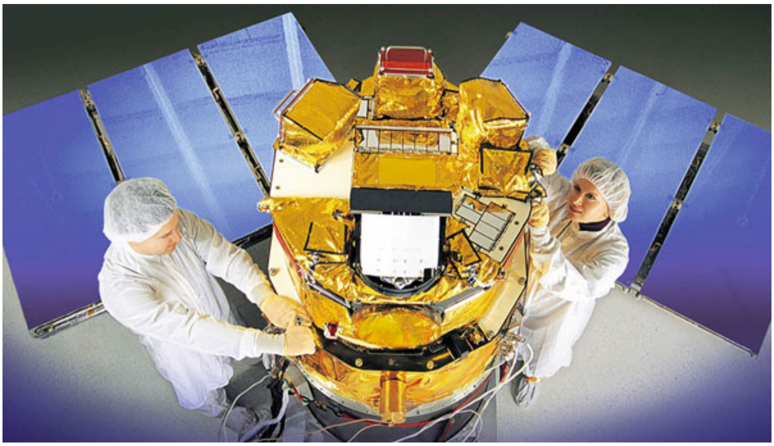


Figure 9.24. The TSX-5 medium-sized spacecraft. (Photo courtesy from Orbital Science Corporation).

TSX-5 flew two major experiments—the Space Test Research Vehicle-2 (STRV-2), a Ballistic Missile Defense Organization (BMDO) sponsored experiment that itself was comprised of seven sub-experiments, including one provided by the UK—and the Compact Environmental Anomaly Sensor Experiment (CEASE), provided by the US Air Force Phillips Laboratory.

Orbital Sciences Corp (Orbital) was the prime contractor responsible for the bus, payload integration, and in this case the launch vehicle, a Pegasus XL rocket. Participants included all the various experiment provider organizations including JPL (the lead for STRV-2), engineering support contractors including the Aerospace Corporation, and the mission operations organization (Space and Missile Systems Centers Detachment 12). A more complete discussion of this mission can be found at www.aero.org/publications/crosslink/summer2001/04.html.

In the case of TSX-5, the IPT structure helped resolve a variety of technical challenges during development and I&T—particularly solar array deployment, several thermal issues, a ground system data incompatibility problem, and a timing anomaly that was identified late at the launch site—by allowing all stakeholder organizations to rapidly communicate and analyze the problems, options, and subsequent resolution plans including retest at multiple levels.

This communication could be performed most efficiently and effectively using the IPT approach, especially during the time-critical I&T and pre-launch phases where timely decision-making was imperative.

Mission Budgets and Examples

Budgets for mid-sized space missions vary as widely as their mission requirements and are driven by a variety of factors including:

- *Technical requirements for both bus and payload*—for example, a precision pointing bus like the Joint MilliArcsecond Pathfinder Survey (JMAPS) may require higher precision attitude control components than is typical, plus significant performance modeling and software development—driving costs up. Alternatively, a communication mission like the Orbcomm second-generation (OG2) with relatively relaxed pointing requirements, and where the payload also serves as the TT&C capability, may allow a much cheaper bus solution.
- *Degree of technical development necessary to achieve mission requirements, also known as Technology Readiness Level (TRL) maturation.* Reuse of existing designs in proven configurations helps keep costs down. Development of any kind—whether hardware or software—adds cost. It is worth negotiating hard in the early design phases to minimize development and maximize the use of previously proven designs—unless the whole purpose of the mission is to demonstrate new technologies. In that case, risk factors must be mutually agreed upon between customer and contractor, and applied to those higher risk areas in the form of budget and schedule margin.
- *Number of units procured, at the component, subsystem, or system level*—any quantity greater than one introduces the opportunity to reduce cost on $N+1$ units, assuming all nonrecurring effort has been accomplished on the first unit. Even more cost savings can be achieved if multiple units are ordered concurrently, rather than sequentially.

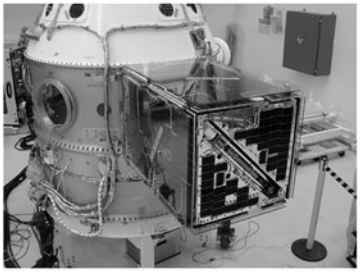
- *Launch approach*—launching as a primary payload on any given launcher is almost always more expensive than launching as a secondary, but mission requirements for orbit parameters, launch schedule, and other factors may not allow a choice in the matter.
- *Contract type*—rule of thumb is that a fixed-price contract, where the contractor takes the financial risk of growth, is more expensive at the proposal phase than a cost-plus type contract for the same scope—because the contractor must build in sufficient cost margins to cover their risk if costs are not guaranteed to be reimbursed. Fixed-price contracts are normally applied where development risk is limited or at least largely quantifiable. Cost-plus type contracts acknowledge the customer's acceptance of cost growth risk—though there may often be provisions where that risk is shared with the contractor via award fee criteria that penalizes growth, or other incentive fee provisions. Both types of contracts are used in mid-sized missions depending on the nature of the program. Most missions whose primary purpose is technology demonstration are cost-plus-fixed fee (CPFF) or some form of cost-plus-incentive or—award fee (CPIF or CPAF), given that their primary mission is to incorporate new technologies that are inherently risky. Most STP missions and the Operationally Responsive Space (ORS) TacSat series are good examples. The exception may be the case where a "standard bus" approach is used—enabling the same design to be utilized for multiple missions and payloads with only minor (if any) technical changes. Commercial missions, particularly multisatellite constellations, very often utilize firm fixed price (FFP) contracts, under the premise that any initial development risk is offset by the low recurring cost of the production phase, supporting reasonable profit expectations on the entire program. OG2 is again a prime example of a commercial program that utilizes a FFP contract despite development of new designs for both bus and payload.

The following examples show the wide range of mid-sized mission costs and their distribution—with total spacecraft costs ranging from less than \$5 M in quantity (OG2 for 18 spacecraft) versus bus-only costs nearing \$40 M for precision-pointers with highly mission-specific requirements like JMAPS.

Note that all figures were obtained from open sources, published articles, and press releases.

- TSX-5 total mission cost at \$85 M (contracted in 1996, launched in 2000, operated for 2 + years). Of that total, bus + LV contract was \$25 M to Orbital on a fixed price basis (as TSX-5 was actually the fifth in a series that included the STEP 1–4 missions), roughly 50/50 cost split between spacecraft and launch vehicle. Remainder of budget was two payloads plus mission operations.
- Orbcomm Gen-2–18 SC + payload + dispensers for three launches at total of \$117 M (awarded 2008). Launch contract at \$45 M. Both of these are fixed-price contracts.
- JMAPS bus only—\$37.9 M in 2010, including payload integration and launch support. Contract type is cost-plus, given the demanding technical requirements and new payload design.
- First STP-SIV bus, including payload integration and launch support—\$26 M in 2006 (part of IDIQ contract up to \$110 M). This contract vehicle is cost-plus, though fixed price was contemplated for the second bus and beyond, plus long-lead hardware buys that enabled faster bus integration schedules (Figure 9.25).

STPSat-1
First STP mission designed specifically for ESPA launch



STPSat-1 on ESPA Ring

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Figure 9.25. STPSat-1, the first STP-SIV medium-sized spacecraft. (Photo courtesy from Comtech AeroAstro).

Program Management Helpful Hints

A hallmark of successful programs is frequent and positive communication between the stakeholders.

This is enabled by the IPT organization structure, but that is just one mechanism for parties to exchange information. A web-based or other hosted server that contains all necessary program documentation, and is accessible to all the participating organizations (with access restricted to need-to-know areas), is typical in many current programs, although this is made more challenging by the frequency and sophistication of cyber attacks, making some companies leery to host them. Regular meetings are also useful so long as that approach does not venture into overkill.

Most effective is proactive, informal, and honest communication between the various management teams—either by frequent phone and e-mail contact, or face-to-face as often as practical.

As in any relationship, it is essential to build trust early in a program, particularly between customer and contractor, and communication of both good and bad news (along with a plan to address the bad news) is critical.

The information that is conveyed in more formal monthly or quarterly management reviews should contain no surprises, particularly to the customer, and should be merely a synopsis of what they already know.

Formal program reviews (i.e., SRR, PDR, CDR, etc.) are also an important communication tool, as they often attract reviewers who are not involved in the program's day-to-day activities—but again, should generally be presentations of information that is already well known, not a venue for bringing up controversial nonconformances or design options.

Formal reviews should be proceeded by more informal, working technical sessions between contractor, customer, and any other reviewing organizations—to present the design or test results and address any major comments—with the goal of significant reduction in the number of findings and/or action items out of the formal review.

Larger and thus more visible programs are somewhat dependent on these formal reviews, as they demonstrate achievement of well-defined milestones and act as gates for entering subsequent program phases (i.e., starting integration and test, or shipping flight hardware for the next integration phase).

Successfully passing them—on the first try, without the need for "delta" or follow-up reviews—again serves to increase customer confidence and the likelihood of continued high-level support (including funding).

Contract changes, while not inevitable, happen so frequently in space programs that they may seem so.

Requirements changes, launch date movement, funding constraints, and other factors over the multiyear duration of most programs typically result in one or more contractual actions.

Change of any kind will almost certainly impact cost and/or schedule, often both, and so for small-to-mid-sized programs there is frequently a concerted effort to minimize changes.

The primary situation to avoid is where there is disagreement between customer and contractor over whether a particular item actually constitutes a contractual change. Requirements "clarifications," different interpretations of SOW, technical specifications, or other contractual documents, delays in CFE's or other outside deliverables, ambiguous requirements for "technical interchange support" where such support is unquantified, may all be sources of cost growth to a program—and also a source of debate whether they constitute actual changes in scope.

Thus, it is really critical to establish the program cost, schedule, and performance baseline—including specific lists of assumptions if any were made during the proposal period and making them part of the contract—such that changes to that baseline are easily quantified.

This short-circuits lengthy justifications and potentially painful negotiations, all of which can erode trust and damage working relationships if taken to an extreme.

As most of us in this industry are painfully aware, the US Government, like other government customer organizations worldwide, is often faced with funding continuity challenges, particularly for the DOD and NASA—key customers for this class of space mission. Operating under "Continuing Resolution" scenarios without an approved fiscal year budget and thus with the possibility of program restructuring once a final government budget is agreed, is a fact of life for many programs.

Delays in receiving contracted funding increments in a timely manner even under approved budgets is also a management issue faced in many if not most government programs.

These scenarios present many challenges to the program's management—how to continue program progress while minimizing schedule impacts, particularly if funds are not available to put key subcontractors under contract, and to maintain team continuity.

In times of limited funding, top priority should be given to maintaining the core program team and make incremental forward progress on key schedule milestones.

Options may include modifying the entry criteria for those milestones, particularly design reviews, to enable at least partial completion (recognizing that delta-reviews may be necessary).

The other challenge is keeping track of schedule impacts that result from those funding delays (and associated cost growth) such that change proposals or other equitable adjustments can be made to the contract. Rules of thumb here are first, make sure the current contract baseline is very clear—such that changes to it can be easily identified—and second, to obtain written contractual direction from the customer identifying the schedule and funding assumptions against which any change proposal should be developed.

Try to avoid multiple "what if" scenarios if possible, as repeated replanning activities are a major resource and time drain.

A final word on the importance of good "people management" over the course of a successful program. Many books are written, classes taught, and team-building exercises undertaken to try to achieve a highly effective and successful team dynamic.

Achieving this goal in a space program can be challenging with a crew composed of sometimes-introverted engineers who would just as soon drive a computer and churn out analyses as go to time-consuming meetings with real humans—and where the Program Managers are often engineers themselves and not necessarily trained or skilled in all aspects of people management. Program management is sometimes viewed as a necessary evil rather than the skilled profession it really is.

A successful Program Manager's primary goals should be to recruit and assemble the right staff in key positions, and then create an environment where they can succeed—in the form of tools, facilities, training, establishment of clear roles and authority, and perhaps most importantly, protection from unnecessary distractions and elimination of nonvalue-added processes.

Emphasis too should be placed on meeting employee's individual goals—for promotion, learning, adding new experiences, etc.—and aligning those individual goals with program goals to the greatest degree possible.

Watching a great team perform well is one of the most satisfying aspects of being a Program Manager.

Acronyms

ACTS	Advanced communication technology satellite
ADCS	Attitude determination and control system
Adscr	Annual debt service cover ratio
AGREE	Reliability of electronic equipment
AIT	Assembly, integration and test
AIV	Assembly, integration and validation
AOCS	Attitude and orbit control system
APU	Auxiliary power unit
AR	Acceptance review
ASI	Agenzia Spaziale Italiana
ATP	Authorization to proceed
ATV	Automated transfer vehicle
B-2-B	Business to business
BFI	Briefings for industry
BFN	Beam forming network
BMDO	Ballistic missile defense organization
BOE	Basis of estimate
BOL	Beginning of life
BUS	Satellite platform
CAPEX	Capital expenditure
CASC	China aerospace corporation
CBS	Cost breakdown structure
CCN	Contract change notice
CDR	Critical design review
CEO	Chief executive officer
CER	Cost estimating relationship
CFE's	Customer furnished equipments
CGWIC	China Great Wall Industry Corporation
CIA	Central Intelligence Agency
CIPE	Comitato Interministeriale Prezzi
CNES	Centre National des Etudes Spatiales
CNSA	China National Space Agency
COMSAT	Communications Satellite Corporation
CPAF	Cost plus award fee
CPFF	Cost plus fixed fee
CPIF	Cost plus incentive fee
CPU	Computer power unit

M. Spagnulo et al., *Space Program Management: Methods and Tools*,
Space Technology Library 28, DOI 10.1007/978-1-4614-3755-0,

CR	Change request
CRYO	Cryogenic
CSG	Centre Spatial Guyanese
CWG	Carrier Working Group
DD	Definition document
DDQC	Design development and qualification cost
DEV	Development
DFM	Design for manufacturability
DFT	Design for testability
DISPC	Cost of disposal operations
DLR	German Aerospace Agency
DOC	Direct operations cost
DoD	Department of Defense
DTH	Direct to home
DVS	Documento di Visione Strategica
DVT	Design verification tests
EAC	European Astronaut Center
EAR	Export Administration Regulations
ECSS	European Cooperation for Space Standardization
EEE	Electrical, electronic, and electromechanical
EIM	Engineering interface model
ELDO	European Launcher Development Organization
ELV	European Launch Vehicle SpA
EM	Engineering model
ENG	Engineering or engine
EOL	End of life
EQM	Engineering Qualification Model
ERNO	ERNO Raumfahrttechnik GmbH
ESA	European Space Agency
ESO	European Southern Observatory
ESOC	European Space Operations Center
ESP	European Space Port
ESP	European Space Policy
ESPI	European Space Policy Institute
ESRIN	European Space Research Institute
ESRO	European Satellite Research Organization
ESTEC	European Space and Technology Center
EU	European Union
Eumetsat	European Meteorological Satellite Organization
EutelSat	European Telecommunication Satellite Organization
EVMS	Earned Value Management System
FCC	Federal Communications Commission
FES	CER figure for engine with solid propellant
FET	Field effect transistor
FFP	Firm fix price
FIST	Fully integrated system test
FM	Flight model

FOC	Full orbital constellation
FPGA	Field programmable gate array
FRR	Flight Readiness Review
FY00K$	Thousand dollars referred to year 2000
GANTT	Henry Laurence Gantt diagram
GDP	Gross domestic product
GLOW	Gross lift off weight
GMES	Global Monitoring Environment and Security
GOV	Governmental
GPS	Global Positioning System
GRC	Glenn Research Center
GSA	Galileo Supervisory Authority
GSE	Ground support equipment
GSLV	Geostationary Satellite Launch Vehicle
GSM	Global system for mobile communications
GTO	Geostationary transfer orbit
H/W	Hardware
IA&T	Integration, assembly and test
ICD	Interface control document
ILS	International Launch Services
IM	Integrated model
IMP	Integrated management plan
IMS	Integrated master schedule
IntelSat	International Telecommunication Satellite Organization
IOD	In-orbit-delivery
IOP	Indirect cost of operations
IOT	In-orbit-testing
IPDT	Integrated product development teams
IPPD	Integrated product and process development
IPT	Integrated product teams
IRL	Integration readiness level
IRR	Internal rate of return
ISAS	Institute of Space and Aeronautical Science
ISO	International Organization for Standardization
ISRO	Indian Space Agency
ISS	International Space Station
ITAR	International Traffic in Arms Regulations
ITT	International Telephone and Telegraph
ITU	International Communication Union
JAXA	Japan Aerospace Exploration Agency
JV	Joint venture
LCC	Life cycle cost
LEM	Lunar landing module
LEO	Low earth orbit
LEOP	Low earth orbit phases
LeRC	Lewis Research Center
Lldscr	Loan life debt service cover ratio

LSC	Launch services contract
LSP	Launch services provider
LV	Launch vehicle
MBA	Multi beam antenna
MBB	Messerschmitt Bolkow Blohm
MeteoSat	Meteorological satellite
Meuro	Millions euro
MIL-STDs	Military standards
MIUR	Ministero Istruzione Università e Ricerca
MMI	Man–machine interfaces
MYr	Man year
NAL	National Aerospace Laboratory
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency
NCC	Network Control Center
NPV	Net present value
NRC	Non recurring cost
NRO	National Reconnaissance Office
OBDH	On board data handling
OCOE	Overall check out equipment
OMB	Office of Management and Budget
OPERC	Operations cost
ORR	Operational readiness review
ORS	Operationally responsive space
OTS	Operational telecommunication satellite
PA	Product assurance
PAM-A	Perigee augmentation motor A
PC	Personal computer
PCD	Production control document
Pcr	Project cover ratio
PCR	Production configuration review
PDR	Preliminary design review
PERT	Program evaluation and review technical
PFM	Proto flight model
PIL	Prodotto Interno Lordo
PoC	Proof if concept or point of contact
POP	Program operating plan
PRODC	Production cost
PSN	Piano Spaziale Nazionale
PSS	Price standard sheets
QA	Quality assurance
QM	Qualification model
QR	Qualification review
R&D	Research and development
RC	Recurring cost
RCT	Reaction control thruster
REF	Reference

RF	Radio frequency
RFI	Request for information
RFP	Request for proposal
RKA	Russian Space Agency
RM	Radiofrequency model
ROE	Return on equity
ROI	Return on investment
RSC	Refurbishment and spare cost
RTDE	Research, technology development
S/S	Sub-system
SAL	Work progress status
SCOE	Spacecraft check out equipment
SES	Societe Europeenne des Satellites
SM	Structural model
SMAD	Small mission analysis and design
SMP	Sinistro Massimo Possibile
SOP	Satellite operators
SOW	Statement of work
SPC	Science policy committee
SPV	Special purpose vehicle
SRM	Solid rocket motor
SRR	System requirements review
SSAC	Space science advisory committee
STD	Standard
SW	Software
SWOT	Strength, weakness, opportunity and threats
TCS	Thermal control system
TEN-T	Trans-European Transport Network
TFU	Theoretical first unit cost
TLC	Telecomunications
TM	Thermal model
TOS	Transfer orbit stage
TRL	Technology readiness level
TSS	Tethered satellite system
TTC	Telemetry and telecommand
TV	Television
TWTA	Travelling wave tube amplifier
URSS	Union of Russian Socialist Republic
USA	United States of America
V-2	Velthashaung 2
VEGA	Vettore Europeo di Generazione Avanzata
WBS	Work breakdown structure
WP	Work package
WPS	Work progress status

Authors' Short Biographies

Marcello Spagnulo, graduated in Aeronautical Engineering, is a space professionals since mid-1980s. After working for many years in major space programs first at the European Space Agency ESA ESTEC establishment in Noordwijk, and then at the Arianespace French consortium in Evry and in French Guyana, he joined Alenia Space Italia (now Thales Alenia Space) and Finmeccanica SpA in Rome covering various management roles. He now works at the Italian Space Agency as Staff of the President. He has written over 50 scientific papers and publications, two books on space exploration history and astronomy, and a professional book on space programs management. He teaches space systems engineering, at the Universities "La Sapienza" and "Tor Vergata" in Rome, and he also teaches professional courses on space systems at the Masters in Space Policy SIOI of the Italian Foreign Affairs Minister.

Rick Fleeter, graduated in Aerospace Propulsion Engineering, is a space professional since early 1980s. He founded and was the CEO of the USA's first company dedicated to small, low cost space, AeroAstro, from 1988 to 2008. He has written the only two books on microspace, Micro Space Craft and The Logic of Microspace. After many years working in major space programs, having developed 24 small spacecraft (which are still nowadays orbiting our Earth or travelling in the Solar System), he escaped to the small satellite environment. He now teaches space systems engineering, design, and technology transfer at Brown University in Providence, Rhode Island and at "La Sapienza" University in Rome. He also works at the Italian Space Agency as consultant. He teaches professional courses worldwide on small space and space program management, and he continues to behave as if small spacecraft can and should take over the world.

Mauro Balduccini, graduated in Nuclear Engineering at the Rome University "La Sapienza," started his professional activity at the end of the 1970s, in the Stress Analysis department of the former Breda Termomeccanica (now Ansaldo), then he moved to the former BPD SpA (now Avio SpaA) as design responsible for space propulsion systems, and then as Program Manager for propulsion and control stages. Later working at the former Alenia Spazio (now Thales Alenia Space), he was platform responsible for the SICRAL1 military Satellite and System manager of ITALSAT2 communication satellite. Back in Avio in the 1990s, he held the responsibility of the Cyclone4 Launcher modernization program, and then he was the first General Manager of the ELV company (Avio 70%, ASI 30%) for the ESAVega Launcher Development Program. He is now at Avio Space Division.

He participated in several specific international technical teams (Ariane 501 failure investigation tech support team) and he holds seminars and courses at the University "La Spaienza" in Rome.

Federico Nasini is in charge of the Finance and Insurance Department at Thales Alenia Space Italia Sp.A., where he has worked since 1998, holding several positions at the financial department. Prior to joining Thales Alenia Space, he worked as a export and project finance manager at Finmeccanica S.p.A., the main Italian industrial group operating globally in the aerospace, defense, and security domain. After graduating in Political Science at La Sapienza University of Rome, he earned a degree in Corporate Finance at the London School of Economics and attended the Credit Risk Evaluation School at I.R.I Management school. He has experience in trade, export, and project finance techniques both in the domestic and international domain. He holds seminars at the Unversity of Cheti-Pescara, G. D'Annunzio and SIOI—Societa Italiana per l'Organizzazione Internazionale, and he is the author of several papers focusing on project financing techniques applied at the Space business.

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